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AROD TEST MODEL HARDWARE

FINAL REPORT

CONTRACT NO. NAS8-11835

MOTOROLA Military Electronics Division



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FINAL REPORT
VOLUME I

Prepared for
INSTRUMENTATIONS AND COMMUNICATIONS DIVISION
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AROD TEST MODEL HARDWARE
FINAL REPORT
CONTRACT NO. NAS8-11835

AROD SYSTEM
FINAL REPORT
AC-F-3065-3

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SECTION I

1. INTRODUCTION

This document is the final report for the design, fabrication, and test phase of the AROD Test Model Hardware program, NASA Contract NAS 8-11835. The effort reported herein was initiated 1 December 1964 and completed 30 November 1966. Study efforts associated with, but independent from the principle design, fabrication, and test effort, are reported separately in references 2, 3, 4 and 5.

The AROD Test Model Hardware development program was initiated in December 1964 as a natural extension of previous feasibility studies and the AROD brassboard program. These previous efforts had defined a system concept and a generalized subsystem block diagram. The over-all objective of this program was to implement the system devised in the previous efforts. This would be performed in a manner which would overcome certain functional problems noted in the brassboard equipment and constrained to a minimum physical size and weight consistent with state-of-the-art integrated circuit devices. To accomplish this goal, Motorola was directed by the contracting agency to review various modulation forms and to select a suitable technique which would minimize the demands on hardware precision and stability. Specifically, inter-channel cross coupling was identified as a major concern, as was near-front-end signal correlation in the tracking receiver.

It was then required to implement, with practical hardware, a system which took maximum advantage of the chosen modulation technique.

The program objectives emphasized development of a design compatible with space performance requirements, although the Test Model Hardware itself was required to be satisfactory for an

aircraft flight test program. New techniques and new devices required to accomplish the program goals were encouraged by NASA. However, such techniques and devices were to be used in a manner which could subsequently be qualified for Hi-Rel applications. These basic objectives have indeed been realized in the equipment developed and fabricated on this program.

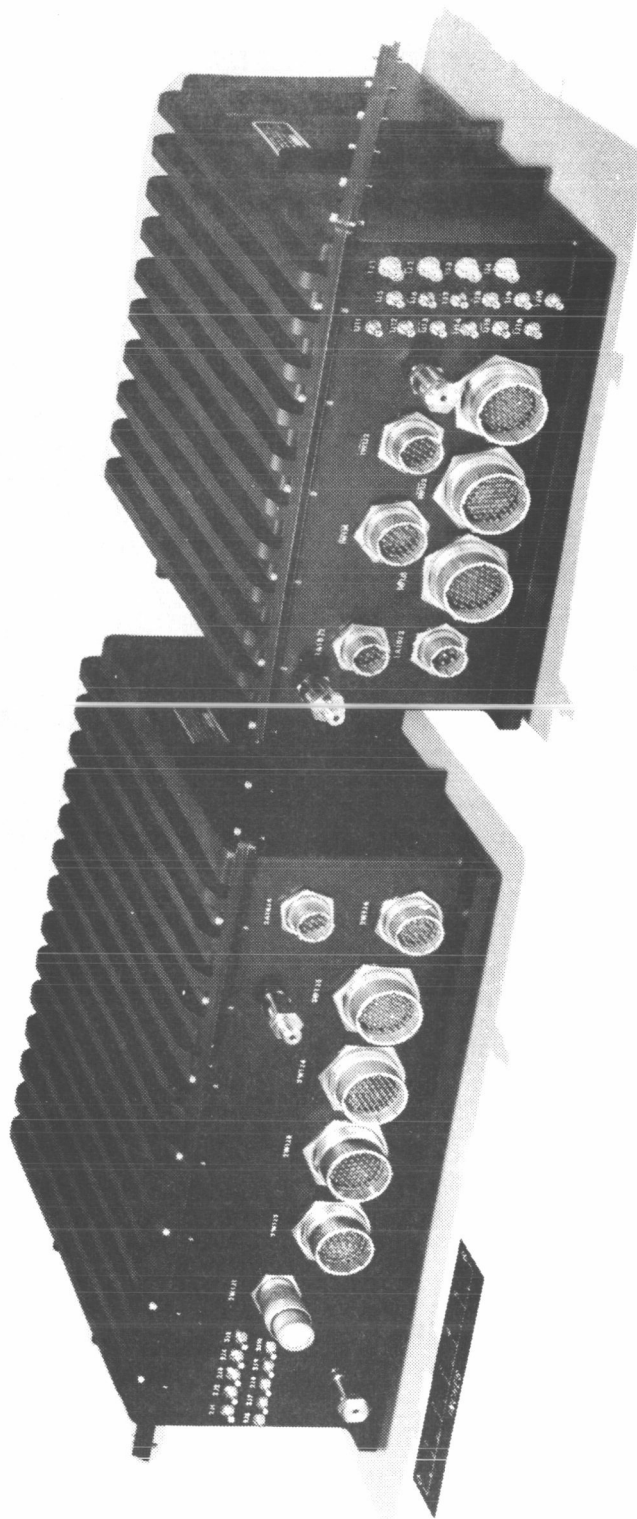
Figure 1-1 is a photograph of the vehicle-borne equipment of the AROD system. This equipment performs the primary functions of signal initiation, range and range rate measurements and overall system control. It is described in detail in section 5 (Volume II) of this report and references 1 and 12.

Figure 1-2 is a photograph of the Ground Transponder equipment. This subsystem performs the basic function of repeating the vehicle signal transmission, translated in frequency. It demodulates the received signal and reconstructs a noise-free replica. It introduces a very small and constant signal time delay. This system is further described in Section 6 (Volume III) of this report and references 1 and 13.

Figure 1-3 and 1-4 illustrates the Vehicle Checkout Equipment and the Ground Transponder Checkout equipment respectively. These units were developed on this program to provide stimulus and measurement signals for evaluation of the vehicle and transponder equipments. Sections 6 and 7 (Volume III) and references 14 and 15 further describe these units.

1.1 SCOPE

The information contained in this report is a documentation of the major program objectives, approach to the major problems, the principle decisions and reasons for these decisions, an evaluation of how successfully the objectives have been met, and finally a limited description of the AROD SYSTEM TEST MODEL HARDWARE.



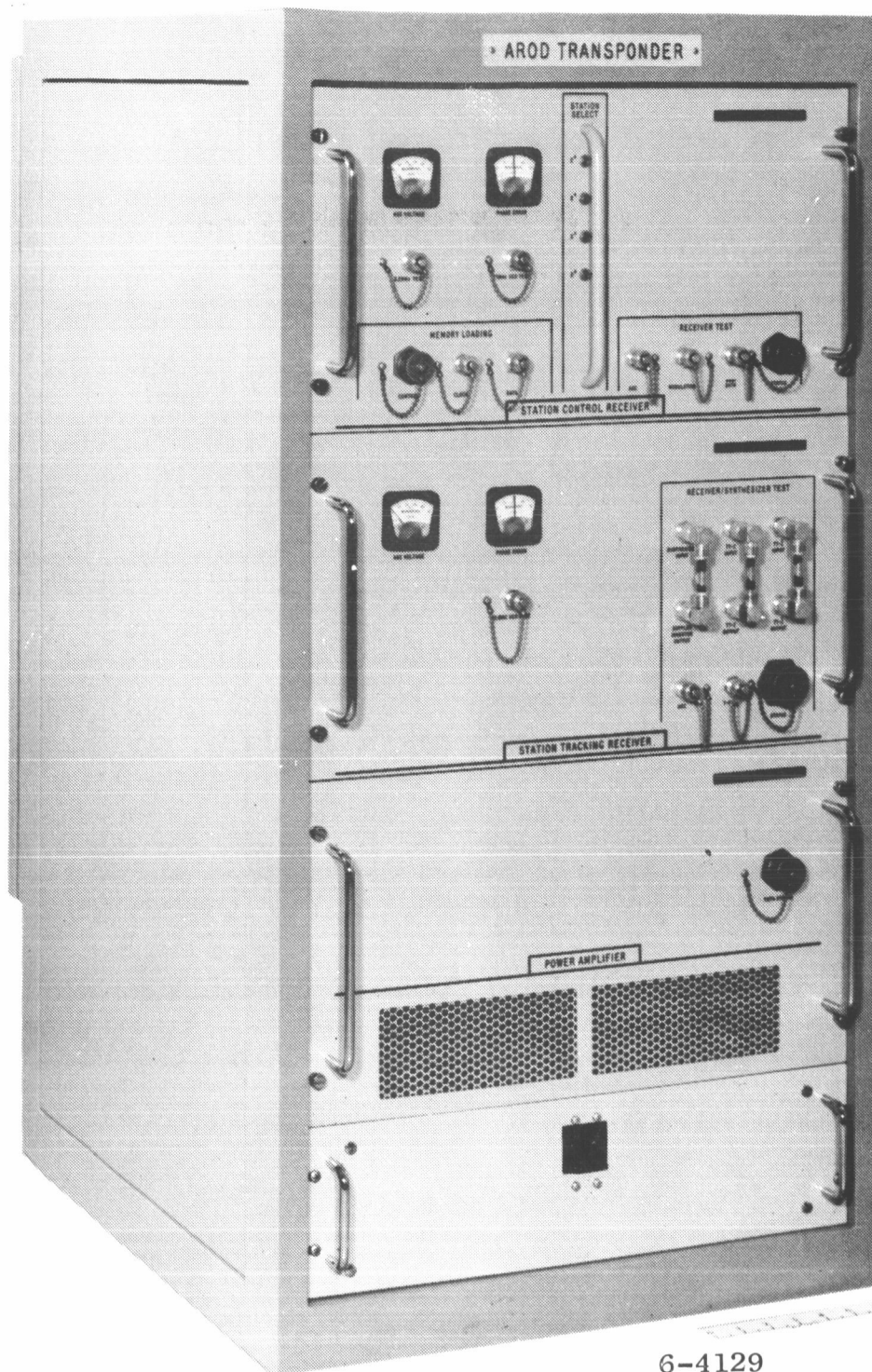
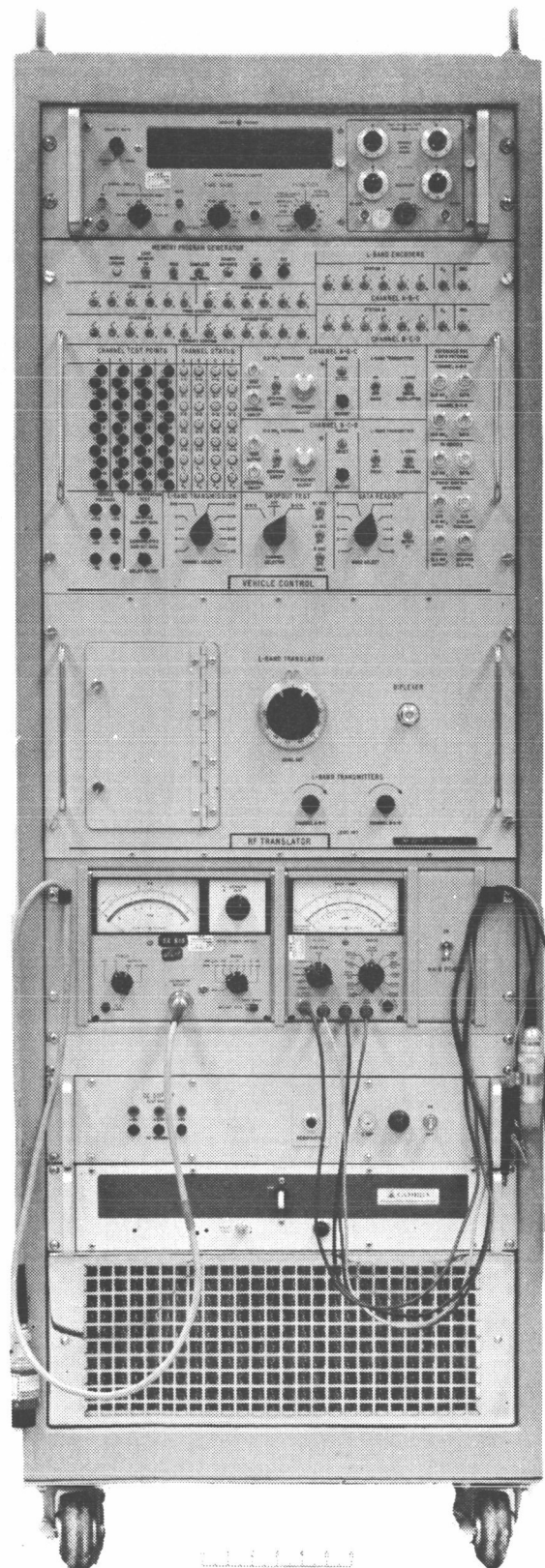
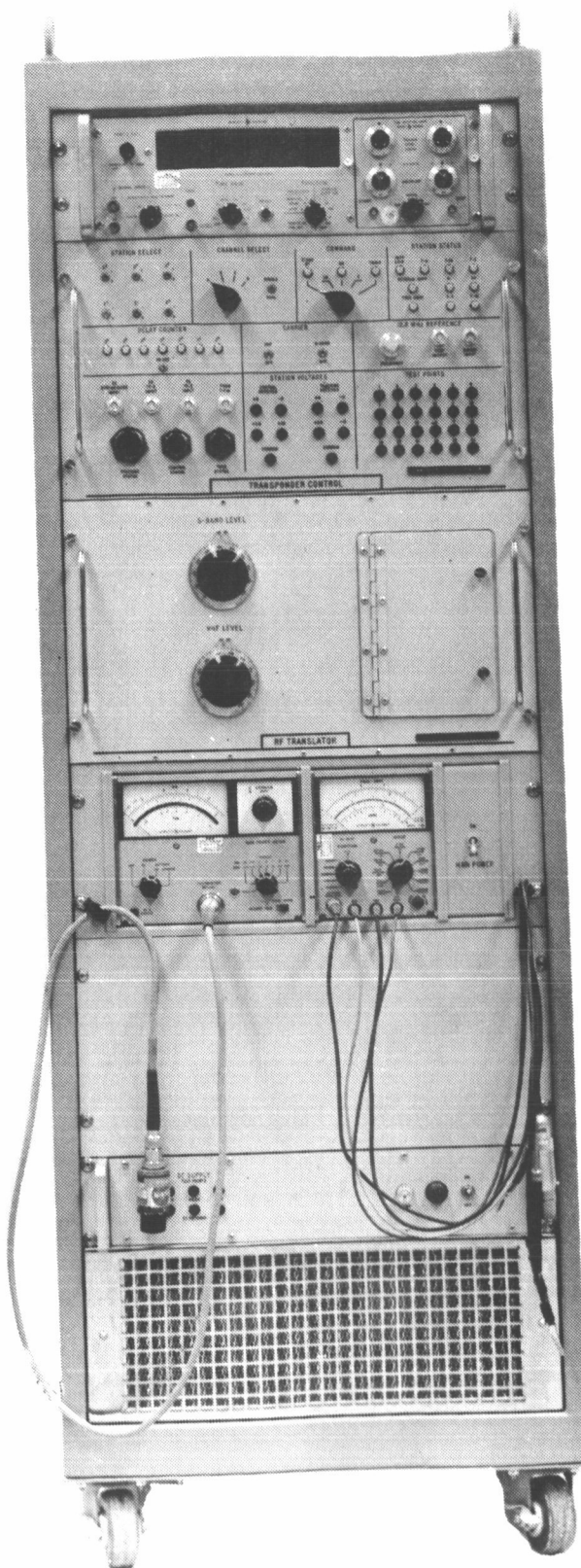


Figure 1-2. AROD Ground Transponder System



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Figure 1-3. AROD Vehicle-Borne Equipment Checkout System



6-4121

Figure 1-4. AROD Ground Transponder Equipment Checkout System

Detail technical information, where necessary to directly support this portion of the final report, is included in the appendices found at the rear of this volume. Further detail, technical and descriptive information is contained in the referenced documents.

Section II briefly reviews the AROD concept around which the basic system was configured.

Section III reviews the chronological history of the program, and indicates the sequence of major program decisions. Technical background and justification for these efforts is included in the appendices of this report as referenced in section III.

In section IV some of the more important performance characteristics are discussed. Initially specified values, analytically estimated parameters and measured characteristics are included. Also discussed in this section are some of the more important technical accomplishments relative to automatic, unmanned, narrow-band communication or range measuring equipment.

Sections V, VI, VII and VIII describe in detail the vehicle, transponder, vehicle checkout, and transponder checkout equipments and subsystems.

SECTION II

2. AROD CONCEPT

AROD is a vehicle based radio frequency system which provides near real time range and range-rate data from multiple ground-based transponder sites. Computation of the vehicle position and its velocity vector can be performed on the vehicle using the data obtained by simultaneous interrogation of three or more sites. The ground stations are completely automatic and require no external timing or synchronization other than the signals from the orbiting vehicle.

The AROD system has been designed with a high degree of flexibility to make it adaptable to a wide variety of missions and applications. This flexibility includes frequency versatility to accommodate varying channel assignments and an adaptable program to determine the site acquisition sequence and criteria for advancing to a new site. Simultaneous tracking of three stations while acquiring a new site is the normal mode of operation, each site being dropped on the basis of an increasing range exceeding a pre-programmed number, and a new site being selected from the vehicle program. This program can be preset or changed in flight. The majority of the AROD system functions are located in the vehicle-borne equipment. To make this practical with present limitations upon size, weight, and prime power capabilities, micro-miniature packaging techniques, integrated circuitry and hardware optimization methods have been extensively employed. This has resulted in several unique solutions to old problems and in the application of integrated circuitry to the radio frequency signal processing equipment. Details of this solution are given in succeeding sections.

2.1 FUNCTIONAL DESCRIPTION

As the AROD system is primarily a vehicle-borne system, the functions of timing, control, station selection, and data extraction are all performed in the vehicle. The remaining equipment associated with the "Transponder Stations", is correspondingly simplified and serves mainly as a means of amplification and frequency translation.

Two radio frequency links between the vehicle and each transponding site are used to perform the AROD functions. A VHF down-link is used for station control and to accelerate the acquisition process. This link essentially performs the duties normally accomplished by the operator in a manned station. It provides an estimate of vehicle direction, vehicle velocity and approximate range, and the turn-on turn-off instructions. Provisions have been made to allow this link to do double duty as a telemetry communications channel simultaneously with its normal AROD functions.

A turn-around S-Band link is used for the range and range rate measurements. The range is determined from the two-way time delay upon the S-Band modulation, and the range rate is derived from the two-way doppler shift of the S-Band carrier. Coherent frequency translation is used throughout to provide the desired accuracy. The range modulation is transmitted as ± 90 degree phase reversals of the carrier and is derived from a binary pseudo-noise (PN) code. This code has acquirable characteristics as it is composed of two subcodes with a fixed time relationship. One of these codes has a low clock rate (the L-code) and is used for rapid initial acquisition and to preset the high clock rate code (the H-code) to approximate synchronization. The range accuracy is derived from the H-code and the unambiguous range capability is provided by the length of the L-code.

The system is fully coherent in the tracking mode. All radio frequency carriers as well as the range modulation, the time generation, and measurement intervals are derived from a common

source located in the vehicle. This eliminates some sources of measurement error and also permits the use of each signal to aid the others during acquisition and tracking. It also provides the means of mutual assistance under conditions of high dynamics or abnormal signal reception.

2.1.1 Functional Subsystems

The AROD functional subsystems and their interconnections are shown in block form in Figure 2-1. These subsystems perform the following services in the acquisition and tracking modes.

1. The Vehicle Frequency and Time Reference is the master time and frequency reference for the entire system. From one stable oscillator are derived the tracking frequencies, the control frequencies, the ranging signals, the time labels for the data readout, and all internal signals needed in the remainder of the system. The carrier frequency signals for the transmitters and the local oscillator signals for the tracking receivers are derived in the programmable variable frequency synthesizers.
2. The Vehicle System Control Logic controls the selection of stations, establishes the sequence of events during acquisition, and contains the memory necessary for station release at the proper range. This subsystem also contains the logic required to assign channels and to make decisions based on the reported tracking status in both the vehicle and transponder receivers.
3. The Vehicle Station Control Transmitter is a vhf transmitter which provides the transponder station with control data, and assists the ground station in the acquisition of the tracking signal. The acquisition aids include minimization of spatial search, Doppler frequency search, and code timing search. This signal also provides an anti-sideband lockout aid to the station tracking receiver. The reception of a standby command by the Station Control Receiver automatically applies power to the remainder of the station equipment.

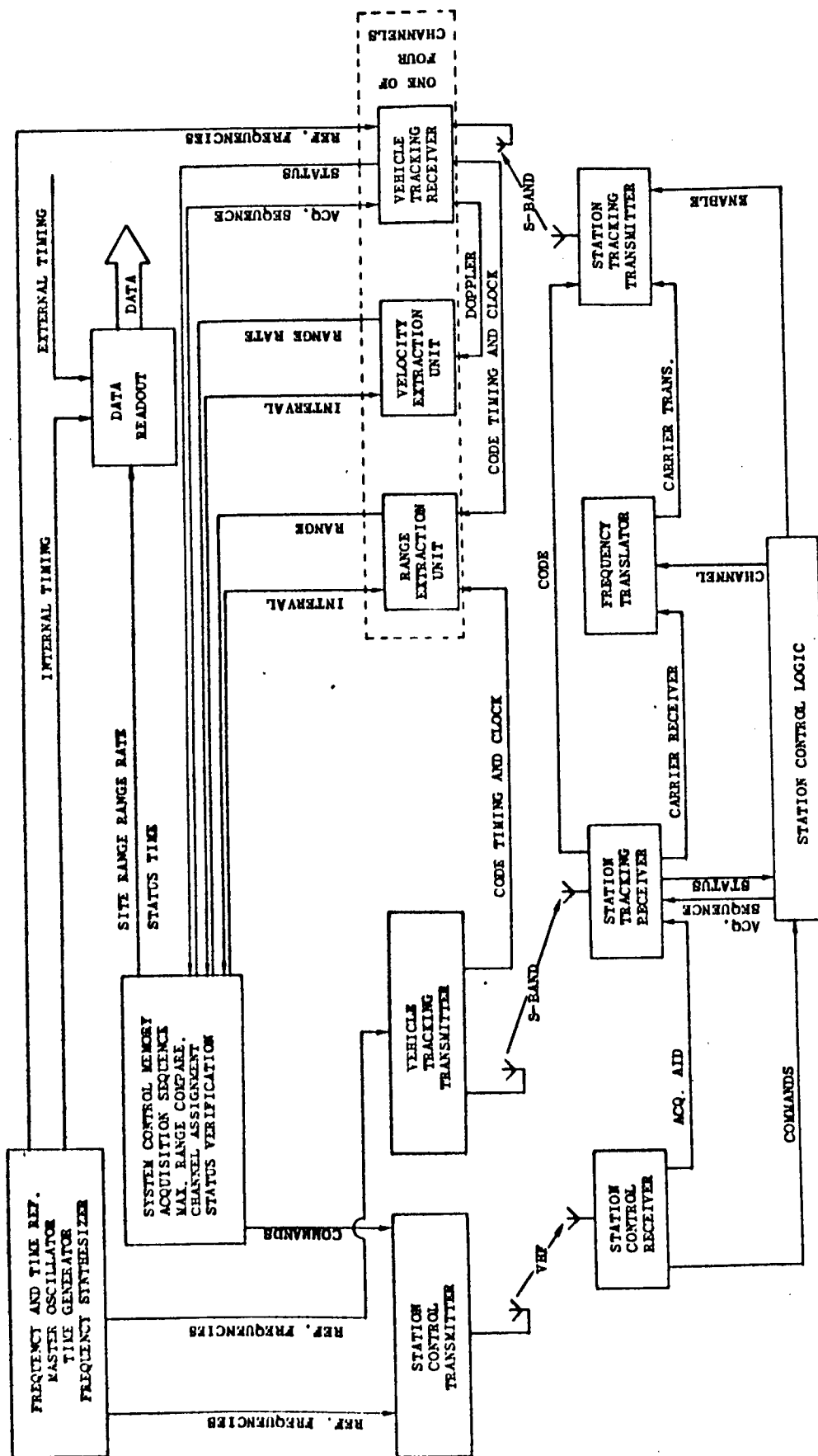


Figure 2-1. AROD Functional Subsystems

4. The S-Band Vehicle Tracking Transmitter is modulated with the Range Modulation signal for the determination of the vehicle position and velocity. To minimize equipment delays, the code timing and high speed clock are extracted near the modulator and delivered to the Range Extraction Unit.
5. The S-Band Vehicle Tracking Receiver contains four channels to process the multiple station return signals simultaneously. The receiver correlates the range modulation upon the received signals and extracts the Doppler velocity from each channel. The receiver also provides detection of the up-link data and provides operating status indications to the System Control Logic.
6. The Vehicle Range Extraction Unit contains the Transmitter Range Modulation Generator. The transmitted range modulation is compared against the received signals, and the time difference is computed. The time delay is sent to the data readout section and to the system control section where it is compared against the preset maximum range. One of these units operates with each tracking receiver channel.
7. The Vehicle Velocity Extraction Unit contains a gated counter which extracts the S-Band Doppler shift for range-rate determination. One of these units operates with each tracking receiver channel. As the gated time interval is determined from the same frequency source as the S-Band carrier there is no bias error in the range rate extraction.
8. In the Vehicle Data Readout Section the information from the Range Extraction Units, the Velocity Extraction Units, the site identification, and the time of the readings are combined for readout to the vehicle computer or to telemetry. The readout rate is nominally four times per second and may be either internally synchronized or may be interrogated by an external non-synchronous timing signal.

9. The Station Control Receiver is the vhf receiver at each of the transponder stations. The receiver provides for the demodulation of control data, supplies a timing signal to the S-band Tracking Receiver for coarse range correlation, and programs the tracking receiver to the expected Doppler shifted frequency.
10. The Transponder Station Control Logic decodes the control information, programs the Station Tracking Transmitter to the desired channel, and provides the sequencing necessary for mode control of the transponder station.
11. The Station Tracking Receiver receives the range modulated S-band signal from the vehicle and correlates the range modulation. The receiver is fully coherent to preserve the Doppler velocity information. A submultiple of the received carrier frequency is directed to the Station Frequency Translator for use in deriving the transmitted carrier.
12. The Station Frequency Translator contains the stable oscillator used in generating the reversed Doppler signal for initial retransmission to the vehicle. It also contains the circuitry necessary to generate any one of four possible coherent transmitter frequencies as directed by the Station Control Logic.
13. The Station Tracking Transmitter amplifies the desired channel carrier signal and modulates this signal with the recorrelated range modulation. The side identification and operating status codes are also applied to the transmitter.

2.1.2 Station Acquisition

The vehicle is capable of tracking four stations at once, or of tracking three stations while acquiring a fourth station. The new station is then received on a channel assignment which corresponds to the empty channel in the vehicle. The tracking data is then continuous while walking over a number of stations which

are called when needed. The control logic is capable of sequencing up to 12 stations in this manner with an add-on capability of controlling up to 60 sites.

The following description of the system operation will assume that three stations are being tracked and one station has reached its maximum usable range while another station is coming into view.

The range readout from each station being tracked is continuously compared against a preset maximum range for that station. When maximum range is exceeded, a return to standby instruction is sent by the vhf Station Control link to that station and a new station is selected from the stored program in the vehicle. This new station has already been ordered from OFF to STANDBY condition by the vehicle. The STANDBY signal is broadcast frequently to all stations in view.

The STANDBY signal initiates a chain of events in each station which receives that instruction. The transmitter filaments are energized starting the warmup cycle; the true frequency of the S-band tracking signal is derived from the vhf carrier and the tracking receiver is programmed to that frequency; the range modulation is estimated from the vhf modulation and an acquisition search is made for the S-band tracking signal. The arrival of an ON signal to that station finds the station tracking receiver completely locked, the ranging signal correlated, and the transmitter awaiting the application of high voltage.

When the vehicle transmits an ON instruction together with the site address and the label for the channel on which to respond, the chosen station decodes this information, selects the appropriate transmitter frequency, and transmits a Doppler reversed signal with the reconstructed range modulation on the desired channel. The Doppler reversal is such that this signal arrives at the vehicle very nearly at the center frequency of the vehicle tracking receiver for that channel.

Simultaneously with the transmitted ON signal, the vehicle tracking receiver is driven to the channel center frequency and a ranging signal search is initiated. When the coarse range is correlated, another instruction is sent on the vhf link ordering the station to its TRACK mode. Upon the receipt of this signal, the station transmitted carrier is swept from the reversed Doppler frequency to the true Doppler or coherent mode of transmission. The vehicle receiver follows this sweep and completes the correlation of the ranging signal. The tracking receiver is then ready for data readout, and the Range and Velocity Extraction Units are enabled.

2.1.3 Tracking Operation

The vehicle-borne equipment performs all of the functions normally assigned to a ground tracking station. The vehicle-borne equipment originates the control and tracking signals and acts as the measurement and data collection point.

The vehicle range relative to a ground station is derived from the time delay between originating the ranging signal and correlating the returned signal at the vehicle. The range measurement is instrumented with resolution of 0.183 meters over an unambiguous out range to 3042 km.

The vehicle velocity relative to a ground station is derived from the Doppler frequency shift on the returned signal and is measured with a resolution of 0.026 meter/second over a span from 0 to 12,000 meters/second.

A time reference is made with an accuracy of ± 0.1 milliseconds of real time with a resolution of 10 microseconds over a 5-minute period. The time label references the time all measurements commenced for every 250 millisecond period.

At an approximate rate of four times per second (to telemetry or external source) the AROD system is capable of reading out simultaneously four range measurements, four velocity measurements and the time label.

The data readout is compatible with either an on-board computer or a telemetry system or both simultaneously.

The terminal equipment which eventually receives the data determines the actual position and velocity vector of the vehicle by triangulation methods based on the measured data and the known location of the ground stations.

2.2 SYSTEM IMPLEMENTATION

The implementation of the AROD concepts has required unique solutions to several basic problems which are magnified by the specific system requirements. The basic problems may be summarized as:

1. providing fully automatic operation
2. providing the required instrumentation accuracy
3. providing rapid acquisition
4. providing multichannel capability in an acceptable frame work of size, weight, power consumption, stability and reliability.

These problems are interdependent, and the consequences of each must be fully appreciated in order to realize an acceptable result.

The need for automatic operation is evident from the system configuration in which the majority of system decisions, programs, and measurements are made in an unmanned vehicle. The consequence of being automatic, however, releases the acquisition process from the limited speed of response of a human operator. As stimuli must be recognized, and appropriate action taken automatically, the possibility of greatly speeding up the acquisition and readout cycle is offered. The penalty which must be paid is that all possible combinations of stimuli and responses must be predicted and correctly programmed.

The provision of high instrumentation accuracy is also linked to the concept of automatic operation. Means of frequent calibration, or compensation of equipment drifts, would be extremely difficult in the absence of an operator. In this sense, accuracy may be equated to stability, and a consideration of potential geometric expansion of errors places a very small contribution to measurement errors in the basic equipment. The approach to realizing this high accuracy involved the stabilization of the major sources of error by placing them inside a very high gain servo loop.

Extremely rapid acquisition times are required particularly when short view times are available from low-orbiting vehicle. This characteristic has been made possible by the automatic feature of the equipment and is further enhanced by a sequential acquisition of a dual code transmission spectrum.

A goal to be approached in navigation and tracking systems is the presentation of the output data in real time. This not only simplifies computation, but in some cases is needed because rapid action must be taken as a result of the measurements. In most cases, slant range and range rate from a single station, no matter how rapidly it may be obtained, is inadequate information to process. A minimum of three measurements to different locations will be needed to uniquely determine the relative position and velocity vector of the vehicle. A multichannel capability as opposed to a sequential interrogation of these locations preserves the near real time aspect of the system. It does, however, raise a host of potential implementation problems, such as control of interchannel interference, intermodulation and minimization of the required spectrum width.

SECTION III

3. PROGRAM HISTORY

This section is intended to provide a chronological review of the principal program efforts. Detail information concerning these efforts is referenced in this section and included in Appendices A through H. Of particular importance is the fact that the AROD System Test Model Hardware program progressed from system concept, through system description and analysis to the final hardware without the step of a complete system breadboard. This could only have been accomplished by thorough analysis and evaluation of subsystem tests to minimize and correct hardware problems at each level.

The AROD program can be divided into four major development phases, which to some extent overlapped chronologically. These phases are:

1. System description phase
2. Breadboard and preliminary design phase
3. Subsystem design and fabrication
4. Subsystem integration and test.

3.1 SYSTEM DESCRIPTION PHASE

Effort during this phase was directed primarily toward formulating and analyzing a system capable of meeting the AROD performance objectives and within the bounds of "The Principles of Operation," Section I, Attachment A of the Contract Work Statement. The system which resulted is described in detail in Motorola Report Number 3065-2-1, AROD System Description, revision 5 dated 1 June 1966 (reference 1).

3.1.1 Selection of Modulation

Primary emphasis was placed on developing a ranging modulation method which provides high performance and which can be acquired rapidly in a manner which does not significantly reduce the long range performance of the system. Several approaches were evaluated early in the program. Among these were various combinations of CW range tones, pseudo-noise codes, phase modulation and frequency modulation.

The selection of an adequate range modulation technique is based on the following constraints.

1. The range modulation must be rapidly acquirable automatically.
2. The range modulation must provide the desired accuracy.
3. The range modulation must provide the desired unambiguous range.
4. The range modulation must provide multipath protection.
5. The range modulation must minimize interchannel effects.
6. The range modulation must provide long term stability.

The two basic techniques which were considered were the use of a number of range tones and the use of a Pseudo-Noise Code sequence. The range tone method is particularly simple to acquire and the speed of acquisition is quite good if all tones are acquired simultaneously. It suffers considerably, however, from interchannel interference. This arises because the desired accuracy at the expected signal strengths require very high modulation frequencies, and direct spectrum overlap as well as intermodulation products which reflect into adjacent receiver channels.

The Pseudo-Noise Code range modulation does not have the interchannel problem but poses problems in initial acquisition.

A typical pseudo-noise code, as used for a range modulation signal, will have an autocorrelation function which is unity for zero time displacement and is bounded by a very small value elsewhere. As a consequence, code alignment can be sensed, but if the code is more than one bit out of alignment there is no information available to indicate the magnitude or direction of the error. The acquisition of the signal must then take place with a "search" of all possible alignment cells. To do this directly requires a formidable amount of parallel hardware, or an unacceptably long search time. This may be greatly alleviated by the use of one of several techniques to reduce the number of cells to be searched.

An obvious method of reducing the number of code cells is the use of a combined code and range tone technique. As an example, one or more high frequency range tones can provide the system precision which is required, and the ambiguity resolution can be achieved with a relatively low frequency ranging code. There are three disadvantages to this approach for the AROD application which outweigh the advantage of its comparative simplicity.

The disadvantages are the lack of interchannel protection due to intermodulation effects, the lack of any multipath protection to the fine range tones, and the necessity of using only a fraction of the received power for the function which is needed most; i.e., accurate ranging.

The required code search time may also be reduced by the use of a multiple code range modulation. The total number of cells will be the product of the lengths of the codes, but the number of cells to be searched can be made to be the sum of the lengths of the codes. This technique has been successfully used in the past and an extension of the method was chosen for the AROD Range Modulation.

The chosen modulation uses two codes. The codes are generated such that the word length of one code (the H-code), after division by a factor of two, becomes the bit length of the second code (the

L-code). Acquisition is performed by sequential search of the L-Code which automatically positions the H-code sequence to very nearly the correct timing. The remainder of the code acquisition is then a restricted search over a very few H-code cells.

This technique has satisfactorily reduced the code acquisition time to an acceptable value and provides the following characteristics:

1. The initial code search is made upon a very low frequency code. The frequency uncertainty of the bit rate due to Doppler shift is correspondingly low and can be ignored.
2. The entire range modulation is coded and offers the benefit of a spread spectrum signal to rejection of adjacent channel intermodulation.
3. The unambiguous range is determined by the word length of the L-code, which, when once resolved, may be eliminated from the transmission.
4. The resolution and accuracy is determined by the bit rate of the H-code, which has the maximum multipath protection.
5. The stability of the relative phasing between the H-code and the L-code is determined by logic operations with no analogue phase adjustments.

3.1.2 VHF Station Control Link

The VHF Station Control Link is utilized for three principal functions. These are:

1. Provide a signal for the ground station antenna system radio direction finding control and tracking.
2. Provide a frequency and tuning acquisition aid to the Transponder S-band Tracking Receiver.
3. Provide communication for control of the transponder by the vehicle unit.

These requirements were considered in selecting a suitable form of modulation for this link.

3.1.2.1 Transponder Antenna Tracking

The Transponder antenna tracking system was not a part of this contract; however, the link design is compatible with requirements for this function.

3.1.2.2 Transponder Tracking Receiver Acquisition

A second function of this link is to aid in the rapid and automatic acquisition of the Transponder S-band Tracking Receiver. In order to accomplish this, the vhf link must provide an accurate estimate of both the Doppler shifted S-band carrier and the range modulation phase. The rapid estimate of these parameters provided the basis for most of the stringent vhf system requirements.

The S-band Doppler estimate is supplied by a coherent vhf receiver whose carrier coherence with the S-band carrier is established in the vehicle frequency synthesizer. The maximum Doppler frequency shift on the vhf carrier is 6,000 Hz and is within easy pull-in range of a coherent receiver. The estimate of range modulation phase is supplied by synchronizing the control data transitions with the range modulation phase in the vehicle equipment.

3.1.2.3 Data Modulation

Two methods of data modulation were considered; PCM/coherent FSK and PCM/PSK/PM. In PCM/FSK, the control data modulates the carrier directly by selecting one of two coherently related carrier frequencies. In PCM/PSK/PM, the control data phase modulates a subcarrier and the resulting signal phase modulates a single carrier frequency.

These systems were compared with respect to theoretical performance and hardware design limitations. The analysis showed that the theoretical performance was almost identical; however, the filter requirements of the PCM/FSK receiver were much more stringent. Therefore, PCM/PSK/PM modulation was selected.

3.1.3 Preliminary Performance Analysis

Preliminary analysis of the AROD system performance was divided into two categories:

1. The characteristics which affect system acquisition,
2. The characteristics which affect the system accuracy.

The results of these analyses are listed in Table 4-1 as the expected performance characteristics and are described in more detail in reference 1.

3.1.3.1 Acquisition Analysis

The AROD concept assumes that the vehicle unit periodically alerts all transponders within range of its presence. Thus, when it is desired to establish a coherent S-band tracking link between the Vehicle Unit and a Transponder Station, the Transponder Station will be locked to and tracking the Vehicle Signal. Acquisition time is then considered as the period following the vehicle "on" command to the Transponder until full signal coherence is achieved and data can be taken. This includes four basic steps as listed in Table 3-1.

The principal requirements for analysis were to optimize system characteristics to minimize the L-code search period and the Doppler reverse period. The other factors were generally small compared to these two major steps and also established by other constraints.

The L-code search rate was established primarily to be consistent with calculated signal strength at the receiver tracking threshold.

The Doppler reverse rate was established as the maximum practical Doppler rate which the vehicle tracking receiver would track when constrained to provide a minimum signal tracking threshold.

TABLE 3-1. Decoding, Coding Time Characteristics

Step	Required Time (sec)	Accumulated Time
1. Vehicle sends "ON" instruction		
Propagation delay	0.007	
Decoding delay	0.040	
Transponder "operating" or ON		0.047
2. Transponder starts L-code transmission		
Propagation delay	0.007	
Average search delay to carrier capture and L-code alignment sensed	1.000	
L-code and carrier locked. Vehicle decodes and verifies site I.D.	0.300	1.354
3. Instruct Transponder to Track		
System Control Logic Cycle delay (avg)	0.080	
Propagation delay	0.007	
Decoding delay	0.040	
Doppler reverse swept 100 kHz/sec	1.000	
Apply H-code at end of sweep, Transponder in full track		2.481
4. Transponder transmits that it is in track with Doppler reverse removed		
Propagation delay	0.007	
Decoding delay	0.300	
Vehicle applies H and starts H search	0.400	
Vehicle S-band system acquires		3.188

3.1.3.2 System Accuracy Analysis

The front-end correlation technique employed in the AROD tracking receivers is new and unique in tracking receiver concept in that it minimizes the delay through the receiver and also minimizes the effects of hardware drift and variations.

In order to estimate the final equipment range accuracy performance, analyses were conducted on the Equipment Error Sources, Range Loop Performance, and Signal to Noise Analysis. The results of this analysis predicted a total range bias error in each tracking receiver of 2.42 nanoseconds (0.32 meters of range).

Since the implementation is fully phase coherent, no bias error is present in the velocity data.

This analysis is further detailed and explained in section 5 of reference 1.

3.2 BREADBOARD AND PRELIMINARY DESIGN PHASE

With the release of the AROD System Description Report (reference 1), the major program effort was shifted to solve the problems of hardware design and fabrication. Initially, preliminary design specifications were prepared for all equipment subsystems. From this, certain subsystems were selected for detailed breadboard design and evaluation, other subsystems were designated for minor circuit breadboarding and prototype design. In some cases where the problems associated with electrical performance of devices and circuits presented very little risk, the designs proceeded directly to the final package design.

The major problem areas which were undertaken in this phase can be categorized as follows.

1. Breadboard design and evaluation of a Transponder S-band tracking transmitter and a Vehicle S-band tracking receiver for the purpose of evaluating the modulation, demodulation characteristics and certain critical circuit problems.

2. Selection of standard parts, selection of monolithic integrated circuits digital family, standardization and design of hybrid integrated circuits for application to the r-f circuitry and digital memory.
3. Preliminary package design including module configuration standardization, overall package evaluation, and subsystem mechanical and electrical interfaces.
4. Definition of requirements for the Vehicle Borne Equipment Checkout System and for the Ground Transponder Equipment Checkout System. Definition of the functions to be performed and modeling of designs to perform the required functions.

3.2.1 S-Band Subsystem Breadboarding

The purpose of the S-band subsystem breadboarding effort was two-fold. First, a number of system characteristics which had been analytically studied required verification and detailed evaluation. Second, new circuit implementations which were required to perform the necessary functions needed evaluation. The breadboarding of the functional elements was scheduled to permit the earliest possible measurements of those characteristics which were critical to the program success.

The breadboard system consisted of portions of the station tracking transmitter, the vehicle tracking receiver, and the vehicle frequency synthesizer. The tests were planned to utilize as much of the final equipment design as possible at an early date. After initial evaluation, additional portions of the system were added in a logical sequence to the breadboard to increase the scope of the tests.

The initial breadboard tests were designed to experimentally verify the following characteristics:

1. Detailed information about the control of spurious sidebands.

2. Experimental measurements of the cross correlation properties of the selected code sequences. These tests included intermodulation and crosstalk with a second transmitter channel.
3. Operation of the receiver preset techniques.
4. Verification of the automatic acquisition cycle.
5. Loop responses and transient behavior.
6. Acquisition, tracking, and data thresholds.
7. Overall system stability, RFI susceptibility, adequacy of gain and phase margins.

This set of tests was primarily exploratory although in several cases quantitative information was required to prove the applicability of the selected approach. It was possible to obtain only gross information about range and velocity accuracy with the initial breadboard.

Reference 6 documents in detail the tracking receiver design resulting from this effort.

3.2.2 Selection of Parts

The majority of the electrical parts used in the AROD Test Model Hardware can be classified in one of three categories.

1. Conventional discrete parts,
2. Monolithic integrated circuit devices,
3. Hybrid integrated circuit devices.

3.2.2.1 Discrete Devices

Discrete devices were selected from standard catalog parts for which a Hi-Rel equivalent was available. The more frequently used of these parts are itemized in Appendix E and F.

3.2.2.2 Monolithic Integrated Circuits

Monolithic integrated circuit devices were selected for the general purpose digital applications. The characteristics of a

number of standard available families were compared against the system requirements of RFI, speed, power, fan-out, and size. Of the various devices available when this comparison was made, several indicated advantages in some characteristic. The final selection of the Philco MW/3 family was based on the optimum trade-offs of factors applicable to the AROD equipment.

3.2.2.3 Hybrid Integrated Circuits

Nine basic types of hybrid integrated circuits were designed for general application throughout the Vehicle and Ground Transporter Equipment. Several variations of one of the nine basic circuits (wideband differential amplifiers) were provided to meet the requirements of a variety of applications in a more optimum manner.

The following table lists the AROD hybrid integrated circuits.

TABLE 3-2. . AROD Hybrid Integrated Circuits

1. Wideband Differential Amplifiers	
High Power	A-45
Medium Power	A-43
Low Power	A-44
2. Square Wave Generator	A-46
3. AROD Core Memory Current Limiter	A-18
4. AROD Core Memory Core Driver	A-19
5. AROD Core Memory Diode Matrix	A-20
6. MOS Switch Driver Amplifier	A-32
7. High Speed Flip-Flop	A-33
8. High Speed Flip-Flop Interface	A-56
9. Mixer Differential Amplifier	A-38

Detail performance specifications and design data for the nine hybrid devices is contained in references 67 through 73.

3.2.2.4 Wideband Differential Amplifier (A43, A44, A45)

The amplifier is basically a differential amplifier with common base outputs. This arrangement provides a high input impedance and a well isolated output. The isolation from output to input is sufficient to provide a high degree of flexibility in circuit design both in linear and non-linear circuits.

The differential amplifier arrangement is designed so that the amplifier may be operated in the limiting mode with symmetrical limiting characteristics and providing no significant phase error.

3.2.2.5 Square Wave Generator (A46)

The square wave generator is basically a differential amplifier which provides symmetrical hard-limiting to low level input signals. The principal application is as an interface from linear circuitry to the digital Milliwatt-3 logic family.

3.2.2.6 AROD Memory Circuits (A18, A19, A20)

The three hybrid integrated circuits used in the AROD MEMORY SYSTEM can be briefly described as follows:

A-18 AROD Core Memory Current Limiter

This device is used in place of a series resistor to limit current flow through the core memory drive lines to a prescribed amount. It has the advantage of allowing a faster current rise time at a lower operating voltage as well as providing more accurate current regulation.

A-19 AROD Core Memory Core Driver

This device is a two-input NAND/NOR gate that controls an output transistor switch. The output switch can handle 300 ma current pulses from a +10 vdc supply provided the duration is less than 5 microseconds and the duty cycle is less than 5 percent.

A-20 AROD Core Memory Diode Matrix

This device is a diode array that contains six (6) diode pairs. These diodes are used in the decoding logic of the memory drive lines.

3.2.2.7 MOS Switch Driver (A32)

The MOS Switch Driver Amplifier is a special purpose hybrid integrated circuit that is used for interfacing MW-3 digital logic circuits and Fairchild Co. metal oxide field effect switches FI 100 and FI 0049. It translates a low logic sense voltage to -15V which in turn enables the MOS switch.

3.2.2.8 High Speed Flip-Flop (A33)

The A-33 is a high speed flip-flop with a typical propagation delay of 3 nanoseconds and output impedance to drive a 50 ohm line. Potential uses for the flip-flop are:

1. Re-timing circuit to improve the phase stability of slower speed logic circuits.
2. High speed logic applications with clock rates on the order of 200 MHz.
3. Digital divider in analog systems to replace the parametric divider in the frequency range of 50 to 275 MHz.

3.2.2.9 High Speed Flip-Flop Interface (A-56)

The A-56 is designed to provide the necessary interface between the Philco MW/3 logic circuits and the A-33 high speed flip-flop.

3.2.2.10 Mixer Differential Amplifier (A38)

The A38 is a basic differential amplifier biased to enhance its operation as a mixer.

3.2.3 Vehicle Package Designs

The initial package design effort was directed primarily toward verifying the validity of the overall package design as described in section 5 under the specified environmental conditions. The most important characteristics requiring confirmation were (a) vibration, (b) structural section necessary for internal pressurization, and (c) thermal characteristics.

A mechanical work-up of a basic package was fabricated and tested to evaluate the design with regard to the structural characteristics.

These tests indicated that the package had no serious resonances which would induce severe vibrations on the electronic parts. The most severe resonances measured were near 220 cps and 1000 cps with amplifications of 10 to 20, and are not considered detrimental. Appendix A contains detail information resulting from the package mock-up vibration testing.

Since the AROD package relies on mounting to a cold plate for heat removal, it was necessary to verify the effect of package pressurization on "warping" of the base plate. A pressure test was conducted on the "mock-up" package to study this effect. The results verified the suitability of the design and are detailed in Appendix B.

The thermal characteristics of a typical integrated circuit package was evaluated by fabricating a complete frame mock-up thoroughly instrumented with thermocouples. The output of the test was a thermal gradient chart which plotted temperature rise as a function of total frame power. This information was used to optimize the mechanical design of the I/C module to minimize thermal gradients and also as a design constraint on the maximum power dissipation in any module. Appendix C documents the detail procedures and results of this evaluation.

The thermal characteristics of a typical RF type module was also evaluated by fabricating a sample module instrumented with thermocouples. The output was a thermal gradient chart indicating temperature rise from components in the module to the module case. This information was used both for design information in the final module package as well as constraint on the electrical design. Appendix D documents the detail procedures and results of this evaluation.

3.2.4 Transponder Package Design

The transponder package was a proven technique. Therefore, no unknowns existed requiring basic package evaluation. Effort in this area consisted primarily of establishing appropriate mechanical and electrical interfaces. Reference 13 provides detail information of the Transponder package characteristics.

3.2.5 Checkout Equipments

In the definition of the checkout equipment, the following general guide lines were used. The checkout equipment must check transponders at their remote sites as well as the laboratory and the vehicle system must be checked out in the aircraft as well as in the laboratory. The vehicle system checkout equipment provided under this contract is not required to check out an inaccessible unit on a launch pad; however, the checkout philosophy must not preclude such a test. Commercial test equipment should be used wherever practical and existing circuit design should be used whenever possible.

The primary function of the checkout equipment is to provide the necessary stimuli and monitoring equipment to check the functional operation of the two AROD terminals and to calibrate the time delay through the AROD system. A secondary function of the checkout equipment is to provide a tool for the engineering evaluation of the AROD system. This function should only be provided if it requires little extra equipment since evaluation is, strictly speaking, not a checkout function.

References 14 and 15 contain detail descriptions and operating information for the Vehicle-borne Equipment Checkout and Ground Transponder Checkout Systems.

3.3 SUBSYSTEM DESIGN AND FABRICATION PHASE

In the subsystems design and fabrication phase of the program the tasks were divided in accordance with both physical and functional interfaces. Certain closely related subsystems, such as the system control logic and station control logic, were designated as a common task to minimize incompatibilities.

In this phase of the program, the equipment subsystems were designed and fabricated in accordance with the performance specifications prepared in the system description program phase. (References 16 through 40.) Each subsystem was tested against a test specification prior to integration in the system, (references 41 through 62).

These test specifications were designed primarily to assure that each subsystem performed according to its specification within practical and realistic testing procedures. Some of the more sensitive requirements could not be evaluated at this level and were postponed for evaluation during the system integration phase. Detail final reports of each task in this phase are contained in sections 6 and 7 of this report.

The checkout equipments were designed and fabricated and tested in accordance with applicable acceptance test procedures references 63 and 64.

3.4 SUBSYSTEM INTEGRATION AND TEST

As each vehicle subsystem was completed and tested it was installed in the vehicle package and the interfaces with the various other subsystems were evaluated. In a similar manner, the transponder subsystems were integrated. During this period, minor interface and power line RFI coupling problems were resolved.

Next, more detailed evaluation was conducted by utilizing the checkout equipments. These tests more accurately simulated the design requirements than had been possible during the breadboard and subsystem test phase.

Detail procedures and test data for the Vehicle and Transponder equipments is contained in reference 5. A summary of the data is contained in Section 4 of this report.

SECTION IV

4. PROGRAM RESULTS

The AROD System Test Model Hardware Program has resulted in vehicle and transponder equipments capable of fully automatic unmanned operation and providing extremely accurate and stable instrumentation measurement characteristics.

The physical size and characteristics of the vehicle equipment are fully compatible with current spacecraft capabilities. Similarly the transponder equipment physical size and characteristics are suitable for convenient transport and remote operation. Thus the AROD concept for accurate, real-time, automatic data measurement from a spacecraft, utilizing unmanned remotely located transponder stations can be realized with the AROD Test Model Hardware Design.

In accomplishing these goals a number of new concepts have been utilized in the areas of packaging, system implementation and application of integrated circuit devices.

The performance and physical characteristics and the new concepts utilized are discussed further in the following sections.

4.1 SYSTEM CHARACTERISTICS

Table 4-1 compares the specified values of the more important system performance characteristics with the calculated and measured values. It is apparent, from Table 4-1 that the actual measured characteristics agree favorably with the specified values.

The following sections provide further discussion of these system characteristics.

More detailed information is given in reference 5.

4.1.1 Maximum Range

For the purpose of comparison, the tabulated maximum range figures have been related to a common base consistent with the antenna characteristics specified in the contract work statement and providing a nominal allowance for cable and connector losses. Figure 4-1 illustrates this concept. Note that the threshold measurements indicate an expected operating range in excess of 10,000 kilometers while allowing up to 8 db for miscellaneous losses.

Table 4-2 lists the threshold measurements for the four vehicle receiver channels. The data tabulated in Table 4-1 is an average of the room temperature performance.

The data in Table 4-2 indicate that the receiver thresholds degrade somewhat at the temperature extremes. It should be noted that these tests were primarily exploratory to determine the equipment characteristics. In each case the thermal conditioning plate temperature was approximately 10°C above the tabulated ambient. As specified, the thermal conditioning plate will be maintained at a maximum of 27°C^* in normal operation and will therefore be within the optimum operating temperature.

Table 4-3 lists the threshold performance of transponder SN/1. These data indicate the transponder performance is well behaved from -24°C to $+50^{\circ}\text{C}$.

4.1.2 Range Accuracy

The range accuracy data presented in Table 4-1 represent the peak to peak variations in range bias error over the expected signal dynamics and temperature ranges. There are three factors which contribute to the measured data. These are

1. Doppler frequency (velocity)
2. signal strength (range) and
3. temperature.

*MSFC Astrionics Laboratory Design Guide Line 09-5A Electronic - Component Housings for Flight Equipment, Design of.

TABLE 4-1. Comparison of Expected Performance with Specified Goals, AROD System

Characteristic	Specified Goal	Design Theoretical Performance	Measured Performance	
			Vehicle Equipment	Transponder Equipment
Maximum range	2000 km ¹	Approx. 20,000 km ¹ 3042 km Ambiguity resolution	>10,000 km ¹ Acquisition threshold = -124 dbm Track threshold = -127 dbm	>10,000 km ¹ Acquisition threshold = -123 dbm Track threshold = -126 dbm
Range resolution	0.25 meter	0.183 meter	0.183 meter	N/A
Range accuracy	±0.5 meters	0.604 meters rms 3.12 meters peak	±0.5 meters	±0.5 meters
Maximum range rate	±12,000 m/s	±13,500	±13,500 m/s	N/A
Range rate resolution	0.02 m/s	0.026 m/s		
Range rate accuracy	±0.015 m/s	0.0148 m/s rms 0.0699 m/s peak	0.09 m/s rms ²	Not measured
Readout rate	4 times/second	4 times/second	4 times/second	N/A
Acquisition time	2 seconds	3.3 seconds	L-code - 1 second average H-code - 0.17 second average	Doppler reverse - 1.2 to 1.6 sec max
Size	1600 cu. in. (V.B.) 20 cu. ft. (G.S.)		1578 in ³	12 ft ³
Weight	55 pounds (V.B.) 300 pounds (G.S.)		51 pounds	290 pounds
Power consumption	150 watts (V.B.) 400 watts (G.S.)		143 watts at 28 vdc	220 watts at 110 v 60 or 120 watts at 28 vdc
Reliability	0.95 for 200 hours (V.B.) 0.99 for 200 hours (G.S.)	.968 .978		
VHF data rate (down link)	Not specified	400 bits/second	400 bits/second	400 bits/second
S-Band data rate (up link)	Not specified	50 bits/second	50 bits/second	50 bits/second

¹Maximum range calculated on basis of specified transmitter power, antenna gain, and receiver threshold.

²Improved to 0.03 m/s during Laboratory Test Program (see ref. 5).

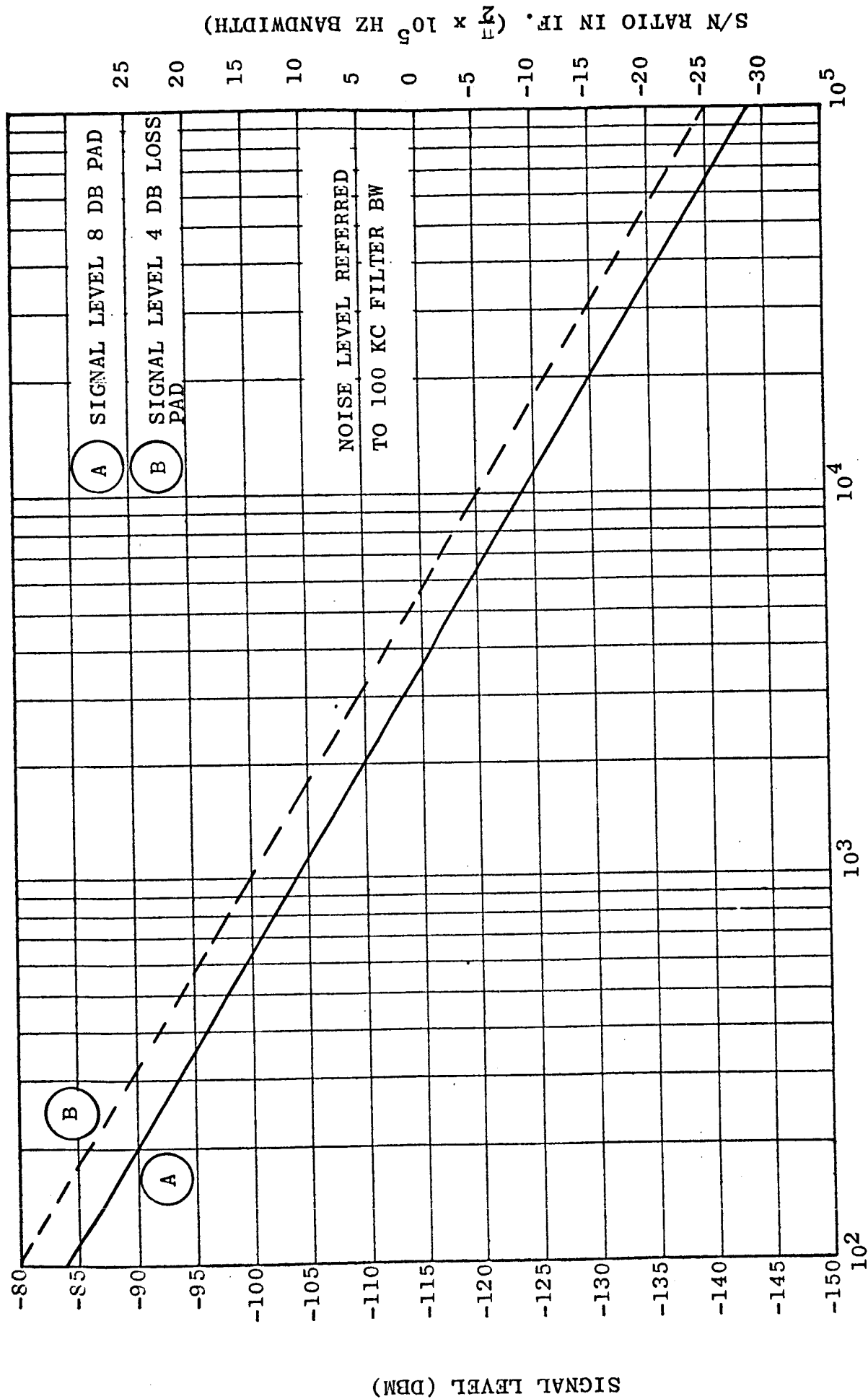


Figure 4-1. Vehicle Received Signal Level vs Range

TABLE 4-2. Vehicle Tracking Receiver Thresholds, -DBM

Test Parameter	CHANNEL A			CHANNEL B			CHANNEL C			CHANNEL D		
	Temperature			Temperature			Temperature			Temperature		
	0°C	+27°C	+40°C	0°C	+27°C	+40°C	0°C	+27°C	+40°C	0°C	+27°C	+40°C
L-Code Acquisition	128.0	127.0	122.0	128.0	128.0	126.0	129.5	128.0	125.5	129.0	129.0	126.5
Doppler Reverse Sweep	125.0	125.5	122.5	124.5	125.5	123.0	125.0	124.0	122.5	124.5	124.0	121.5
L-Code Track	131.5	131.0	129.0	131.5	131.0	130.5	132.0	131.5	130.0	132.0	131.5	129.5
H-Code Acquisition	121.0	123.0	119.0	126.0	126.0	122.0	122.5	124.0	121.0	---	125.0	122.0
H-Code Track	123.0	125.0	123.0	129.0	128.5	127.0	126.0	126.0	124.5	127.5	127.0	125.5

TABLE 4-3. Transponder Tracking Receiver Thresholds, -DBM

Doppler Frequency (12.8 MHz)	Temperature (°C)	L-Code Threshold (dbm)		H-Code Threshold (dbm)	
		Acquisition (-126 nom)	Track (-127 nom)	Acquisition (-126 nom)	Track (-127 nom)
+512	-24	-131	-131	-125	-127
-512	-24	-129	-129	-125	-125
+512	+25	-129	-129	-125	-126
-512	+25	-130	-129	-125	-126
+512	+50	-129	-130	-124	-126
-512	+50	-129	-129	-123	-126

4.1.2.1 Vehicle-Borne Equipment Range Measurement Errors

Figures 4-2, 4-3, and 4-4 illustrate the variations of average range measurement error as a function of these three factors for channel B of the Vehicle-borne Equipment. These data were taken with the vehicle equipment operative with the vehicle checkout equipment.

Notice, that within the expected signal strength range from -75 to -115 dbm, the total variation due to all effects is within the range of +0.7 to -0.3 meters. No significant effects were noted resulting from two or more channels tracking simultaneously. Further information regarding this effort can be found in reference 5.

4.1.2.2 Transponder Equipment Range Errors

Figures 4-5, 4-6, and 4-7 illustrate the variations of average range measurement error as a function of signal strength, velocity and temperature for SN/1 of the AROD Transponder Equipment.

These data were taken with the transponder equipment operating with the transponder checkout equipment.

Although the total variations due to all factors is less than +0.5 to -0.5 meters, the majority of the errors have been traced to the characteristic temperature dependence of the crystal in the modulation tracking loop VCO. Procurement of a better crystal will improve this performance.

4.1.3 Range Rate Measurement Accuracy

The measured performance of the vehicle range rate (velocity) readout data indicated an rms error of 0.3 meters/second peak-to-peak or an rms error of approximately 0.09 meters/second. The tests clearly identified that the majority of the noise was originating in the vehicle tracking receiver local oscillator frequency synthesizer. To expedite further evaluation, it was decided by mutual agreement of Motorola and the NASA Technical

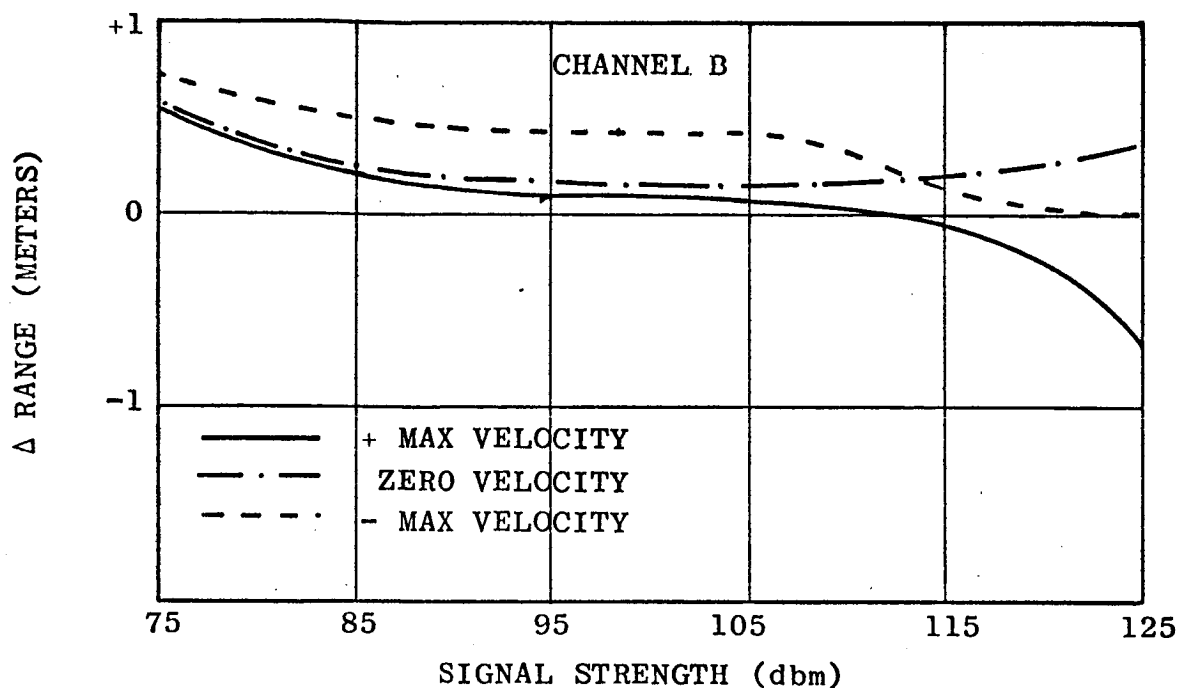


Figure 4-2. Range Measurement Error vs Signal Strength (AROD Vehicle-Borne Equipment, Channel B at 0°C)

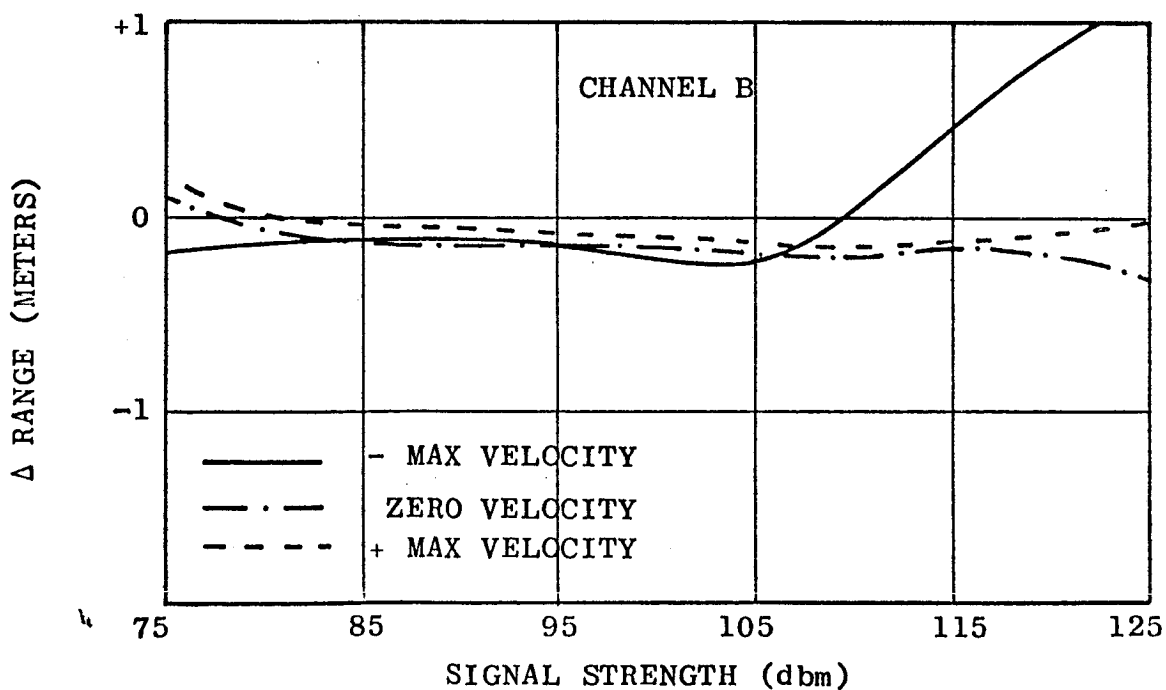


Figure 4-3. Range Measurement Error vs Signal Strength (AROD Vehicle-Borne Equipment, Channel B, Room Temperature)

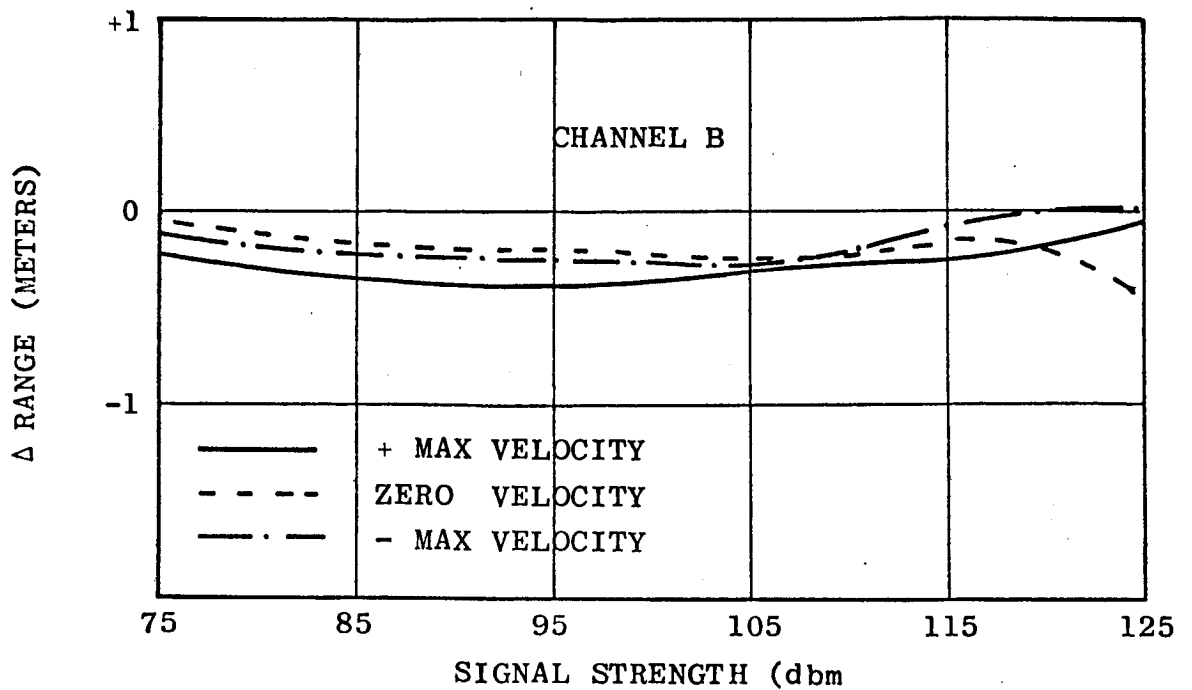


Figure 4-4. Range Measurement Error vs Signal Strength (AROD Vehicle-Borne Equipment, Channel B, 40°C)

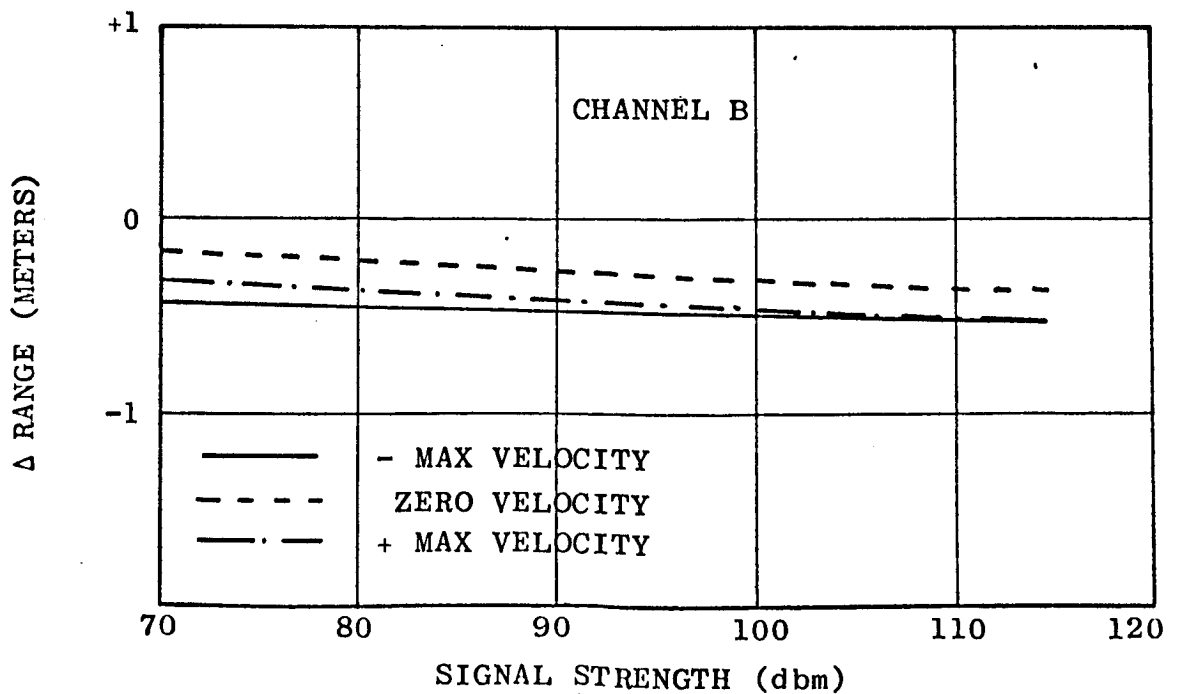


Figure 4-5. Range Measurement Error vs Signal Strength (AROD Transponder Equipment S/N 1, -24°C)

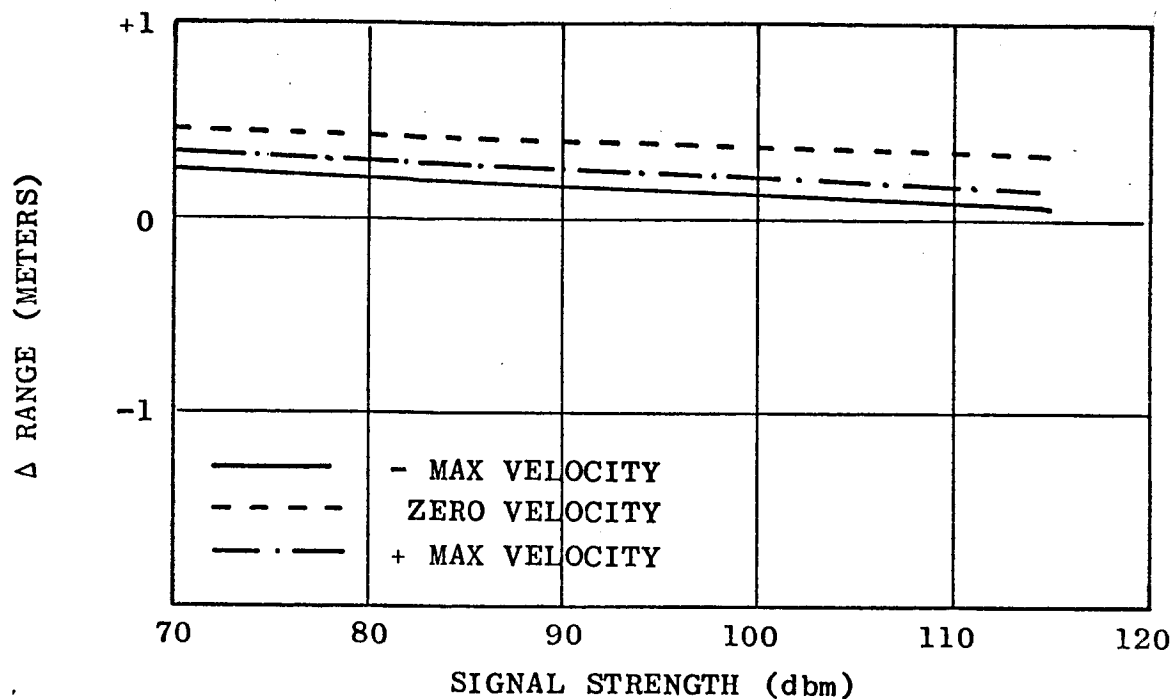


Figure 4-6. Range Measurement Error vs Signal Strength (AROD Transponder Equipment S/N 1, Room Temperature)

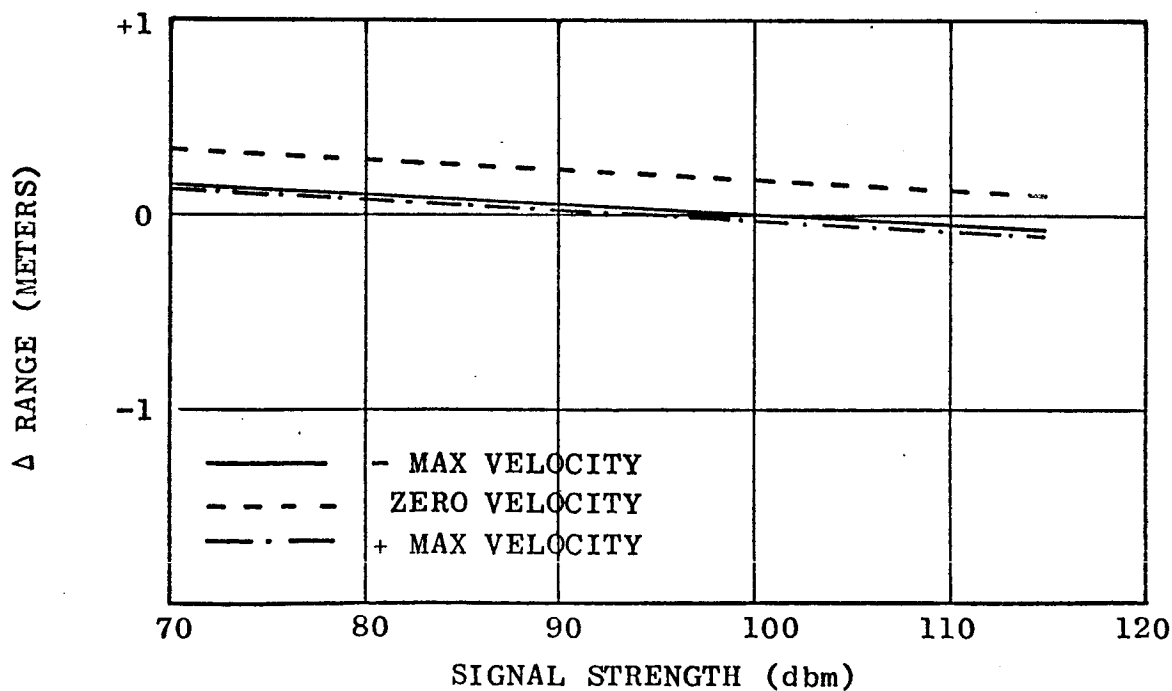


Figure 4-7. Range Measurement Error vs Signal Strength (AROD Transponder Equipment S/N 1, +50°C)

Director, to proceed into the laboratory evaluation program rather than correct this problem at this point in the program.* It should be noted that the data presented represents the rms variance of individual readings. Since the implementation technique eliminates all bias error, further accuracy can be achieved by longer integration periods or by further processing the individual samples.

4.1.4 Acquisition Time

The acquisition process is composed of many steps involving operations by both terminals as well as communication between them. A detail listing of the various steps is contained in reference 1.

Since the checkout equipment was designed to evaluate the various steps of acquisition, it utilizes manual controls to advance from step to step. Thus the time of the individual steps was measured rather than the total automatic acquisition.

The time measured for acquiring L-code and H-code, of 1 second average and 0.17 second average respectively, compares favorably with the time allotted in the analysis of 1 second and 0.4 second respectively. Also the Doppler reverse sweep measurement of 1.2 to 1.6 seconds maximum compares favorably with the allotted 1 second average.

Table 4-4 illustrates the average L-code and H-code acquisition measurements for a number of samples at various operating conditions. The data listed in Table 4-1 is an average of these measurements.

These data indicate that the basic acquisition characteristics agree with the design expectations. Complete automatic acquisition will be further evaluated during the laboratory test program.

*During the laboratory test program, redesign of the vehicle receiver and vehicle transmitter frequency synthesizers reduced total rms noise to approximately 0.03 meters/seconds rms.

TABLE 4-4. Acquisition Time, Seconds

Test Parameter		CHANNEL A			CHANNEL B			CHANNEL C			CHANNEL D		
		0°C	+27°C	40°C	0°C	+27°C	+40°C	0°C	+27°C	+40°C	0°C	+27°C	+40°C
Low Code Acquisition Time	-70 dbm	0.87	1.19	1.45	1.09	1.13	1.55	0.97	1.45	0.61	0.85	1.25	0.40
	-115 dbm	0.67	1.63	1.36	1.13	1.46	1.13	0.97	1.58	0.36	1.02	1.28	0.68
High Code Acquisition Time	-70 dbm	0.30	0.22	--	0.09	0.17	0.12	0.06	0.11	0.22	0.14	0.12	0.32
	-115 dbm	0.75	0.20	--	0.13	0.12	0.12	0.16	0.12	0.16	0.20	0.14	0.18

4.2 RELIABILITY

Appendices E and F contain the reliability analysis for the vehicle and transponder equipments excluding the Traveling Wave Tube Amplifiers. The results of the analysis as shown in Table 4-1 indicates that the required reliability can be achieved by the use of hi-rel parts.

The analysis, as given in Appendices E and F, also indicate that consideration should be given to reducing the number of ceramic capacitors, if possible, in future equipments.

The major reliability efforts for the AROD Test Model Hardware have been directed to the application of integrated circuits. This includes both monolithic and hybrid devices as well as the processes used in assembling and inspecting at each level of construction. Results of this program indicate that high reliability can be realized with these parts if they are screened and tested at the appropriate stages of equipment assembly.

4.2.1 Monolithic Digital Integrated Circuits

The monolithic digital integrated circuits used in the AROD Test Model Hardware are itemized in Table 4-5.

In addition to those listed, approximately 2800 devices were used in breadboards, checkout equipments, test fixtures and stock for spares. The total considered quantity is about 6500 devices.

Failures resulting from known mishandling or over-rated operation were not reported and do not appear on Table 4-5. Table 4-5 lists only failures for which there was known to be no mis-treatment of the device.

The manufacturing defects noted include:

- a. Scratches and spots in the metallization
- b. Pin holes
- c. Necking down of conductors

TABLE 4-5. Monolithic Digital Integrated Circuits,
AROD Test Model Hardware

Type	Vehicle Equip	Transponder Equip (each)	Total	Failures	
				Mfg Defect	Inconclusive
PL 975 Adder	12	0	12	0	0
PL 976 Buffer	305	60	485	0	2
PL 977 Dual Gate	48	14	90	1	1
PL 978 Dual 3 Input Gate	60	9	87	0	1
PL 979 Gate Expander	81	14	123	0	0
PL 980 Gate 4 Input	155	19	212	1	0
PL 981 Half Adder	27	3	36	0	1
PL 983 Qual 2 Input Gate	501	86	759	1	0
PL 984 Register	1247	193	1896	5	5
PL 985 Triple 3 Input Gate	89	17	140	0	0
TOTAL	2525	415	3770	8	10

d. Poor registration

e. Voids in passivation

f. At least one instance of purple plague.

All failures to date were found in the initial I/C module and subsystem test phase prior to August 1, 1966. From that time to Dec. 31, 1966, during system integration and test the equipment was operated for approximately 400 hours without a

failure. The accumulated device hours is then approximately 1,208,000 without a failure. Although these data do not definitely establish a device failure rate, it does support the 0.0005% per thousand hours use in the reliability analyses (appendices E and F).

4.2.2 Hybrid Integrated Circuits

Table 4-6 lists the hybrid integrated circuits utilized in the AROD Test Model Hardware.

These units were extensively tested prior to installing in the equipment to eliminate manufacturing defects. Since the units have been installed in the subsystem, system integration and test has consumed a total of approximately 400 operating hours, by the total number of units listed in Table 4-6 without any failures. This represents 225,600 device hours without failure. This record supports the estimated failure rate of 0.0007% per thousand hours as used in the equipment reliability analysis (appendices E and F).

Table 4-6. Hybrid Integrated Circuits, AROD Test Model Hardware

Type	Vehicle	Transponder (each)	Total
A18 Core Memory Current Lim.	2	0	2
A19 Core Memory Driver	34	0	34
A20 Core Memory Diode Matrix	5	0	5
A32 MOS Switch Driver	48	13	87
A33 High Speed Flip-Flop	10	3	19
A38 Mixer Diff Amp	15	3	24
A43 Low Power Diff Amp	90	34	192
A44 Med Power Diff Amp	66	17	117
A45 High Power Diff Amp	2	0	2
A46 Square Wave Generator	36	12	72
A56 High Speed F/F Interface	10	0	10
TOTAL	318	82	564

4.3 TECHNOLOGICAL ADVANCES

Development of the AROD System Test Model Hardware has resulted in a number of significant technological advances which can be classified in three categories as follows:

1. System
2. Implementation
3. Packaging

4.3.1 System Technological Advances

The AROD concept of automatic unmanned operation imposes a stringent requirement on operational stability. It is therefore, imperative that the modulation concept employed be tolerant of hardware imperfections and variations.

The requirement for fast automatic acquisition necessitated a modulation technique which could be quickly and uniquely acquired.

Equipment Tolerant Modulation

Reference 7, "New Technology Report No. I, Equipment Tolerant Range Code Demodulation Method" describes in detail a significant accomplishment of the AROD program in this area.

Fundamentally, the system employed, utilizes correlation of the modulation signal very near the receiver input. At the correlation point, the timing error is represented by the amplitude of an intermediate frequency carrier. By this technique, the receiver amplifier serves basically as a servo amplifier, amplifying a null or error signal. Phase shift in the amplifier is of little importance, affecting only the loop gain in a function proportional to the cosine of the phase shift angle. Thus delay through the receiver does not affect delay of the signal modulation.

Other systems which use a similar front-end correlation technique represent the phase error of the feedback frequency as the phase error in a much lower frequency. This reduces the

sensitivity of the receiver to internal phase drifts, but does not eliminate its effect on time delay as does the AROD technique.

Acquirable Range Code Sequence

Reference 8, "New Technology Report No. II, "Acquirable Range Code Sequence" describes a Low Speed - High Speed coding technique which permits rapid modulation acquisition in the AROD System.

The technique described differs from other acquirable coding techniques in that it first acquires and locks to a low frequency code, and then acquires the high frequency code. The tracking accuracy on the low frequency code is such that only a very limited search is required to obtain the proper phase of the high frequency code, thus minimizing search time. Also tracking on the low frequency code provides operation of moderate accuracy while searching the high frequency code phase.

4.3.2 Implementation Technological Advances

To satisfy the AROD operational concepts, several new and unique implementation techniques were needed. Specifically the conflicting requirements for a narrow band sensitive receiver with a wide dynamic frequency tracking capability would be difficult if not impossible to implement for automatic operation by conventional techniques. An approach was needed which was tolerant of equipment imperfections and variations. Further, to achieve the package size goals, extensive use of integrated circuits was required.

Phase Lock Loop Frequency Control

Reference 10, "New Technology Report No. IV, Phase Lock Loop Frequency Control" describes the technique employed in AROD to preset the Vehicle and Transponder Tracking Receivers to the expected received frequency and hold until lock is achieved.

This unique feature utilizes a frequency reference to accurately preset the phase lock receiver vco within its lock-in range. The

technique holds the receiver in lock-in range until lock is achieved through the frequency preset loop. When phase-lock is achieved the frequency pre-set loop is deactivated.

Digital Frequency Discriminator

Reference 11, "New Technology, Report No. V, Digital Frequency Discriminator" describes a drift-free digital discriminator necessary to successfully implement the Phase Lock Loop Frequency Control feature described above. This discriminator accurately and without drift determines which of two input frequencies is higher. The output level is either a positive or negative voltage depending upon that decision.

4.3.3 Package Technology Advances

The Packaging Technique employed in the AROD vehicle equipment utilizes standard space proven assembly and manufacturing processes and procedures. It represents a technology advancement in that it contains both integrated and discrete parts, subsystems which are completely digital, a combination of digital and RF, and completely RF in a compatible packaging technique.

A principle objective of the program has been to utilize integrated circuits, in a manner which benefits from the size and performance advantages, and maintains good assembly and inspection procedures. That is, "cramming" as a means of miniaturization was not considered good practice.

Although integrated circuit devices have advanced rapidly in recent years and in many cases provide superior performance to discrete circuits, it is still necessary to perform many functions with discrete parts or circuits composed wholly of discrete parts.

To take advantage of the best characteristics of both type circuits a compatible packaging technique was employed.

Many factors, such as

1. Optimum utilization of space,
2. Producibility,

3. Inspectibility,
4. RFI and noise problems,
5. Vibration and shock, and
6. Thermal problems

were considered in the development of a compatible package.

Digital Subsystems

The digital subsystems are composed primarily of monolithic integrated circuit FEB's, however, some special discrete parts have been used where interface or operation requirements exist which cannot be achieved by currently available FEB's. The all-digital subsystems are packaged as shown in Figure 4-8. In this package the FEB's and discrete parts are interconnected in microharness subassemblies (modules) which are in turn interconnected on a two-sided printed circuit board. This packaging technique, not only permits a mixture of I/C FEB's and discrete parts with efficient utilization of space and weight, but also provides various assembly levels which are readily accessible to work on and inspect. Each frame (group of I/C modules) includes a power line filter module, thus constraining power line conducted noise problems within the particular functions on one frame. Because the FEB interconnect is accomplished largely with microharness and consequently are somewhat isolated from each other, radiated noise problems are minimized.

The microharness module has proven advantageous in applications where the majority of the parts are integrated circuits and only a few discrete parts are required.

Combination Digital and RF Subsystems

The AROD subsystems which are a mixture of digital and RF circuits utilize a compatible package which not only permits a mixture of integrated circuits and discrete parts, but also includes a mixture of circuits which are composed primarily of discrete parts. This, of course, requires a building block or module different from the microharness module. A conventional cordwood module, as shown in Figure 4-9 was used. The dimensions of this

module make it completely compatible with the microharness module and permits application of both subassemblies on a common printed circuit motherboard as shown in Figure 4-10. This packaging has been utilized in the AROD equipment in a complex Frequency Synthesizer subsystem. This requirement includes many interfaces from the digital circuits to the RF circuits and vice versa. The coherent noise problem is of particular importance in this application since it is necessary to synthesize signals, coherently related in frequency, but individually pure or uncontaminated by the related coherent signals.

To combat this problem, the cordwood modules are completely shielded in metal cans and mounted tightly to a conductive ground plane to eliminate RF spray from the circuitry internal to the module. Carefully placed printed circuitry, functioning somewhat as a dielectrically loaded strip line, minimizes radiation from the module pins and interconnections. Careful module functional breakdown is also important to keep the most sensitive low level points inside a shielded module.

These subsystems also employ power supply line filters on each frame to constrain the conducted noise problems within that frame.

The cordwood modules, in addition to providing a subassembly compatible with the microharness module, also has proven advantageous for circuits employing a mixture of integrated circuits and discrete parts which are predominately composed of discrete parts.

RF Subsystems

The RF subsystems in the AROD Vehicle equipment employ the compatible cordwood module discussed above in combination with various VHF point to point techniques as well as microwave techniques.

Overall Package

The complete AROD vehicle equipment is composed of two separate packages containing a mixture of completely digital type frames,

completely RF type frames, frames employing both the digital and RF type modules, compatible microwave functions and a power converter. Interconnection of the frames is accomplished with standard hook-up cable and coax techniques. (Figure 1-3).

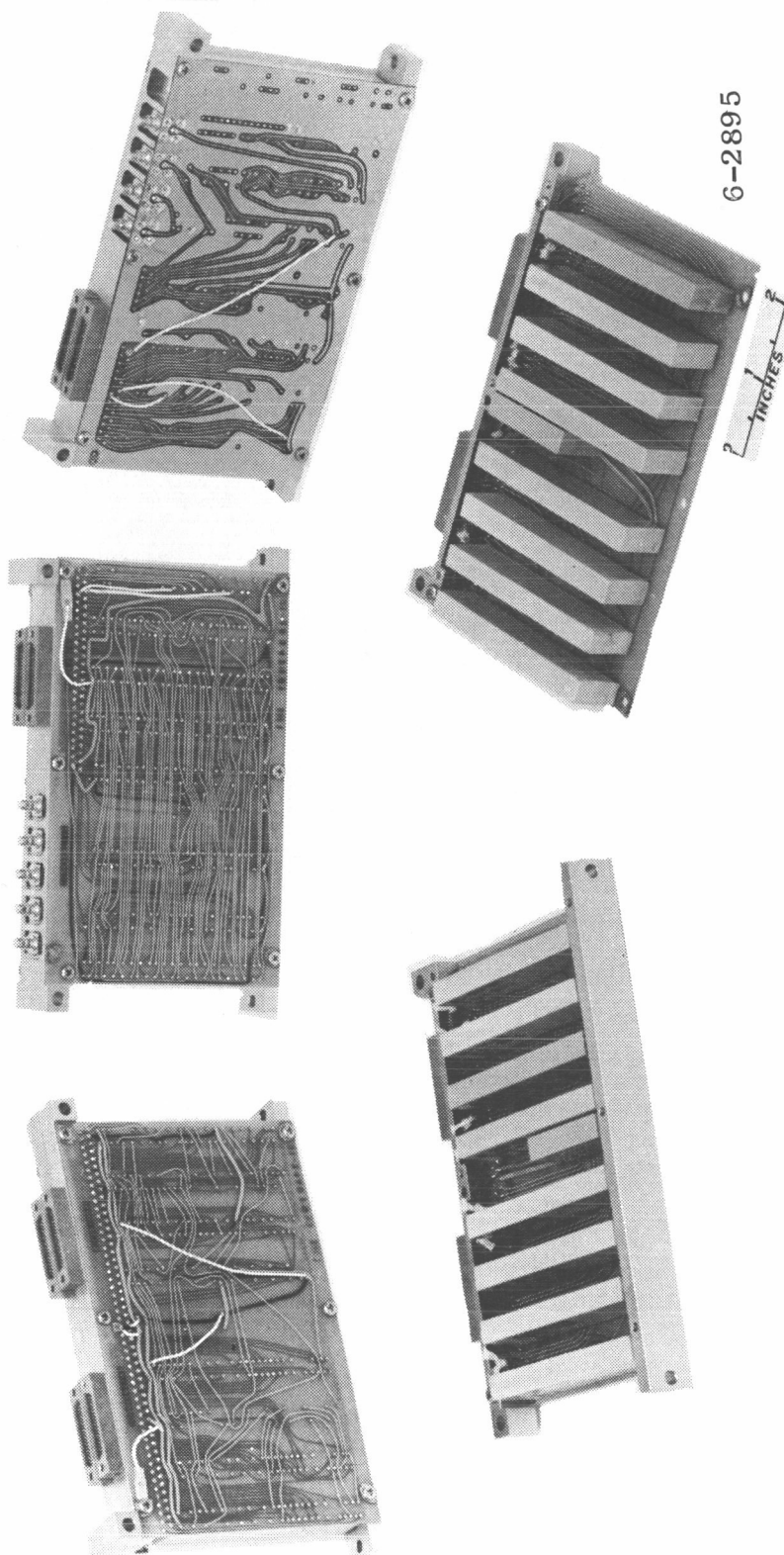
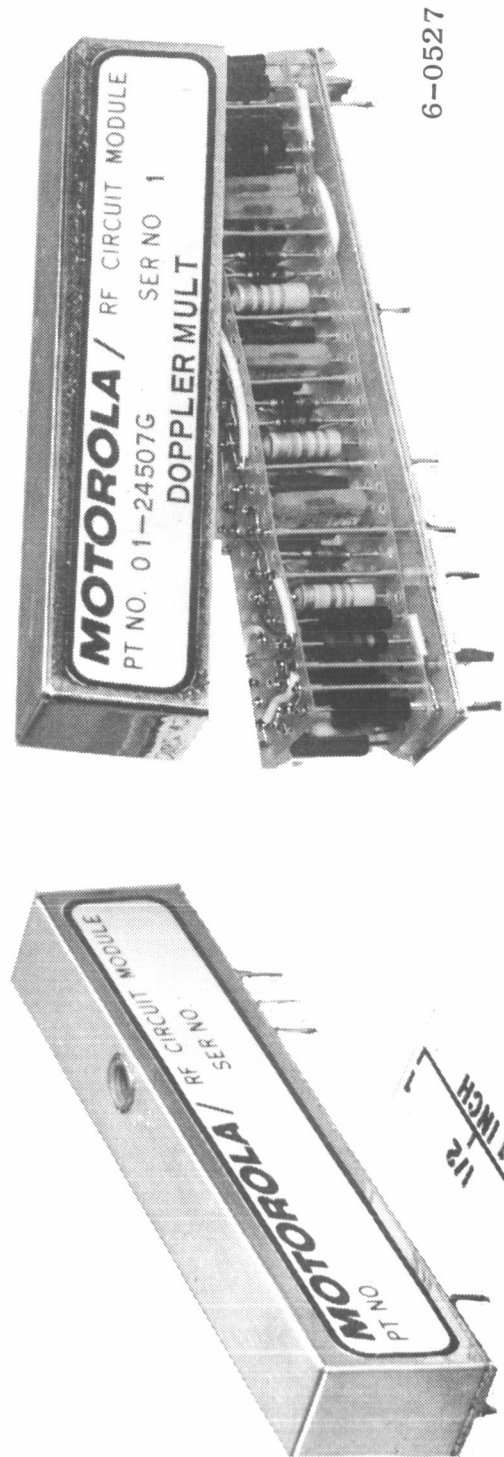


Figure 4-8. Data Measurement Subsystem



6-0527

Figure 4-9. Typical R-F Cordwood Module

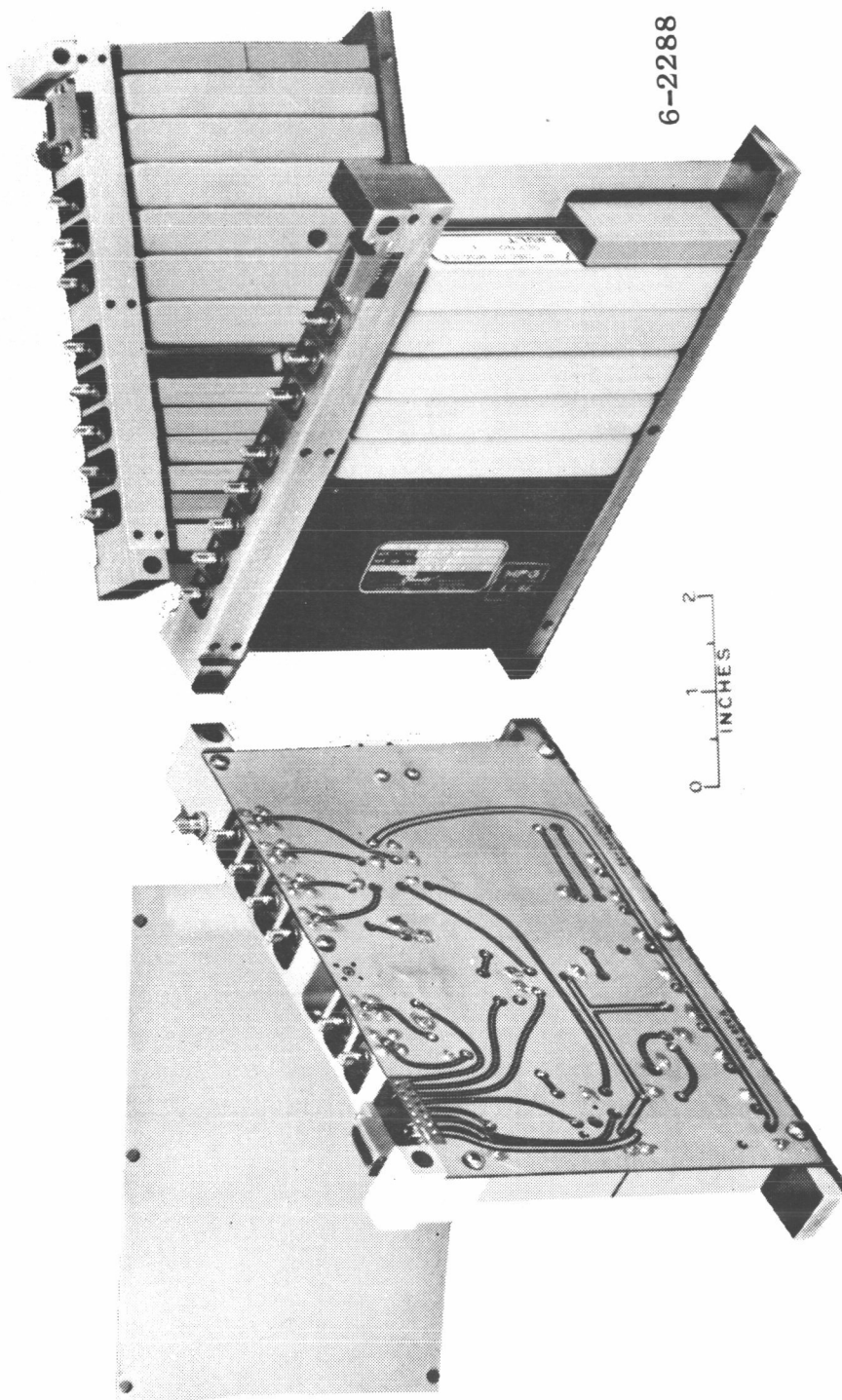


Figure 4-10. Vehicle Frequency Synthesizer

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REFERENCES

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18. Performance Specification Vehicle Control Data Modulator - AROD Mech. Spec. 12-25607F
19. Performance Specification Vehicle Frequency Synthesizer - AROD Mech. Spec. 12-25599F

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AROD Mech. Spec. 12-25620F
21. Performance Specification Vehicle Tracking Transmitter -
AROD Mech. Spec. 12-25564F
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Code Control Subsection - AROD Mech. Spec. 12-25612F
23. Performance Specification Vehicle Tracking Receiver -
AROD Mech. Spec. 12-25604F
24. Performance Specification Vehicle System Control Logic -
AROD Mech. Spec. 12-25611F
25. Performance Specification System Control Logic Memory
Subsystem - AROD Mech. Spec. 12-25623F
26. Performance Specification S-Band Data Demodulator -
AROD Mech. Spec. 12-25636F
27. Performance Specification Data Readout Unit -
AROD Mech. Spec. 12-25616F
28. Performance Specification Velocity Extraction Unit -
AROD Mech. Spec. 12-25617F
29. Performance Specification Vehicle Timing Unit -
AROD Mech. Spec. 12-25618F
30. Performance Specification Range Extraction Unit -
AROD Mech. Spec. 12-25619F
31. Performance Specification Frequency Converter -
AROD Mech. Spec. 12-25650F
32. Performance Specification Vehicle Power Converter -
AROD Mech. Spec. 12-26176G
33. Performance Specification Station Tracking Receiver -
AROD Mech. Spec. 12-25605F
34. Performance Specification Station Control Receiver -
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35. Performance Specification Transponder Station Control Logic -
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36. Performance Specification Station Frequency Synthesizer -
AROD Mech. Spec. 12-25598F
37. Performance Specification S-Band Data Modulator -
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44. Test Procedure Vehicle Master Oscillator 12-24636H
45. Test Procedure Vehicle Tracking Transmitter 12-24602G
46. Test Procedure Vehicle Tracking Transmitter Code Control Unit 12-24607G
47. Test Procedure Vehicle Tracking Receiver 12-23371G
48. Test Procedure Vehicle Receiver Code Control Unit 12-24639H
49. Test Procedure Vehicle System Control Logic 12-24693H
50. Test Procedure System Control Memory 12-24694H
51. Test Procedure Vehicle Data Readout 12-29129G
52. Test Procedure Vehicle Velocity Extraction 12-29115G
53. Test Procedure Vehicle Timing Unit 12-24497G
54. Test Procedure Vehicle Range Extraction Unit 12-24687H
55. Test Procedure Vehicle Power Converter 12-29222G
56. Test Procedure Transponder Tracking Receiver 12-24761H
57. Test Procedure Transponder Code Control Unit 12-24686H
58. Test Procedure Station Control Receiver 12-24749H
59. Test Procedure Transponder Transmitter Synthesizer 12-24587H
60. Test Procedure 3.2 MHz Master Oscillator 12-24589H
61. Test Procedure Station Control Data Demodulator 12-24582H
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64. Acceptance Test Procedure Vehicle Checkout Equipment 12-24762H

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- | | | |
|-----|--|-----------|
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| 67. | Wideband Differential Amplifier Specification
51-29967A13, A14, A15, A43, A44, A45 | 12-24626H |
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| 72. | Specifications for High Speed Flip-Flop Interface A56 Hybrid Integrated Circuit | 12-24664H |
| 73. | Specifications and Test Procedure for Mixer Differential Amplifier (A38) Hybrid Integrated Circuit | 12-24670H |

APPENDIX A

DEVELOPMENTAL VIBRATION TEST

AROD SYSTEM

PURPOSE:

To determine the points of resonance, and the vibration load amplification, that can be expected in various component parts of the AROD electronic package.

SCOPE:

The tests were limited to sections of the structure that support electronic components. Resonances of covers and other portions of structure that do not support electronics are not classified as major or secondary resonances and were not included as part of the test.

TEST EQUIPMENT:

Ling 250 Shacker and Side Table

Ling R-1003 Sine Console

CEC 11 Channel Recording Oscillograph

PROCEDURE:

At the time of test two package configurations were under consideration, one with an eight inch mounting span, the other with a ten inch mounting span. In the interest of time and economy, a single chassis base plate capable of representing both configurations with a simple shift in mounting bolts was built for the tests. The plate mounting is pictured in figure 1.

Nine subassemblies similar to the proposed digital section were mocked up. Weight and construction of the mock up was a duplication of that anticipated for the final units.

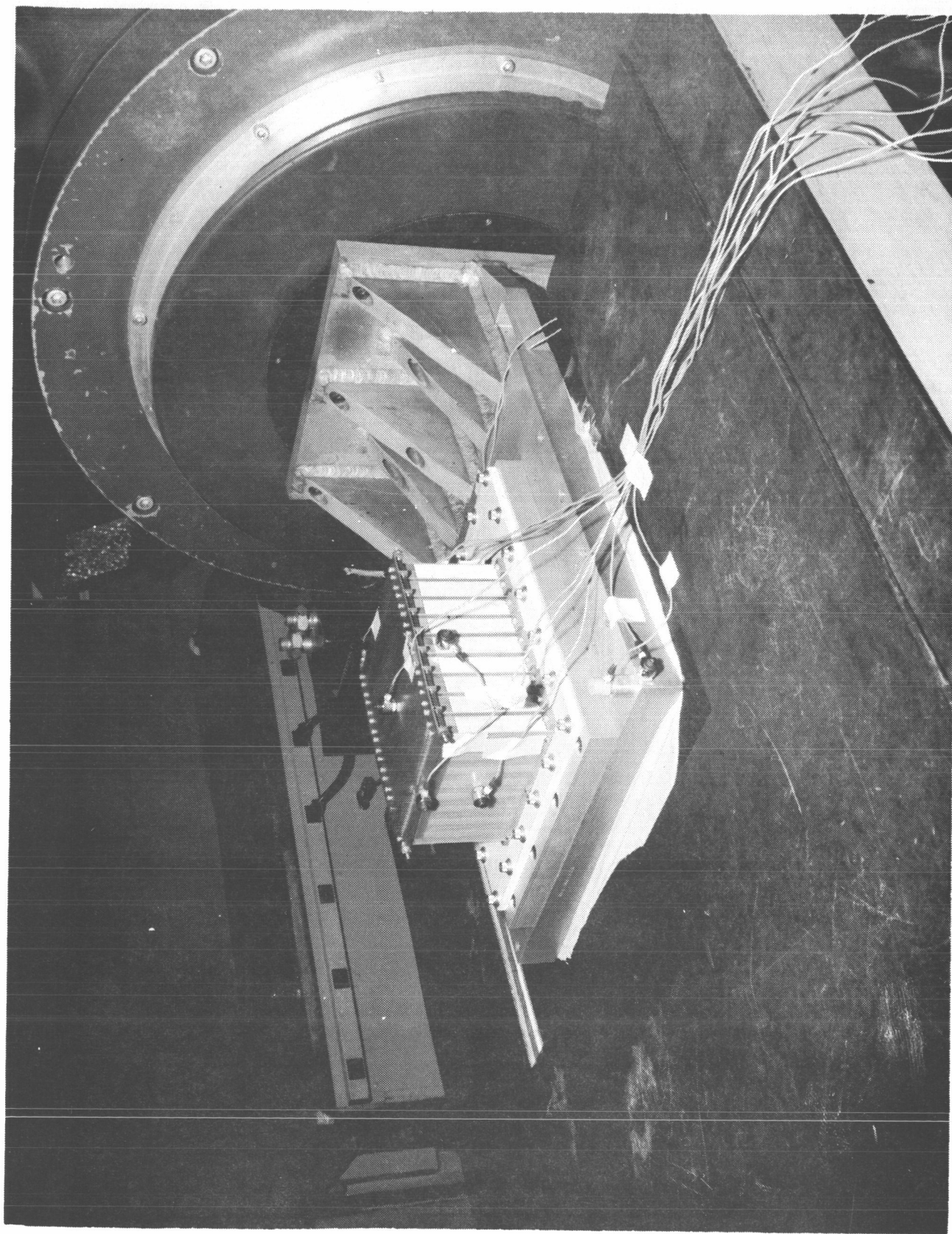
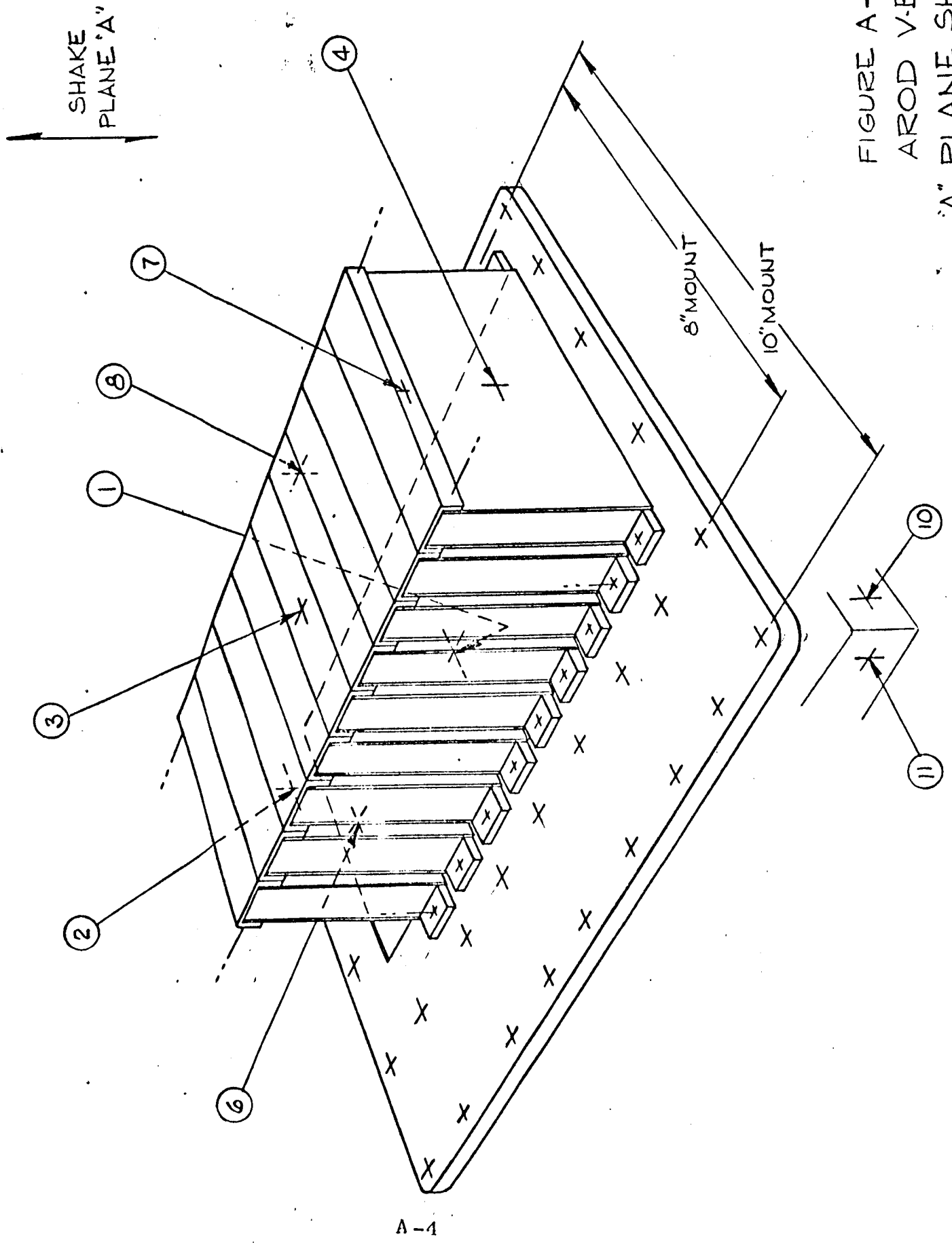


Figure A-1. Typical Shake Test Set-up

FIGURE A-2
AROD V.B
"A" PLANE SHAKE



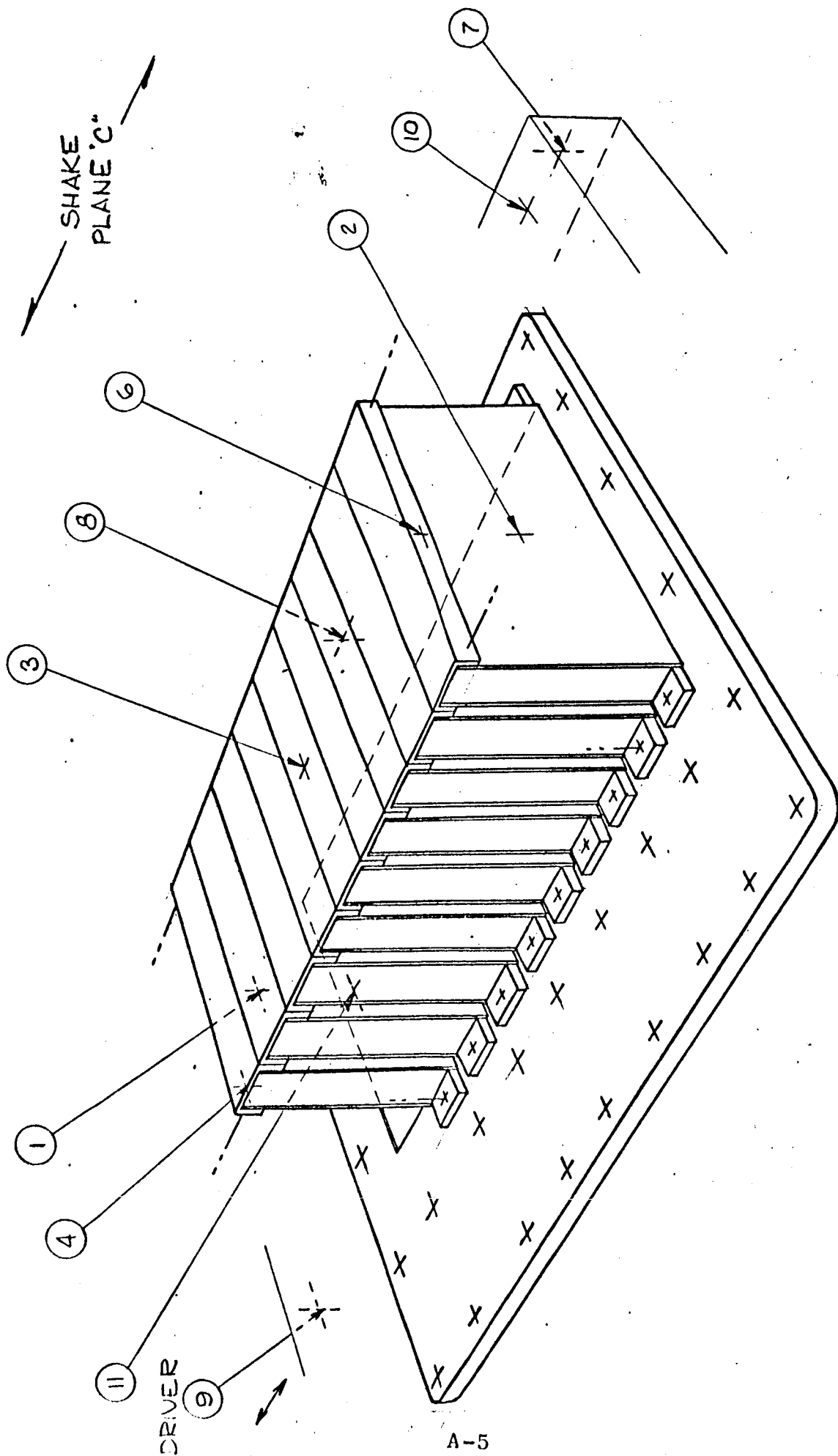


FIGURE A-3

AROD V-B

"C" PLANE SHAKE

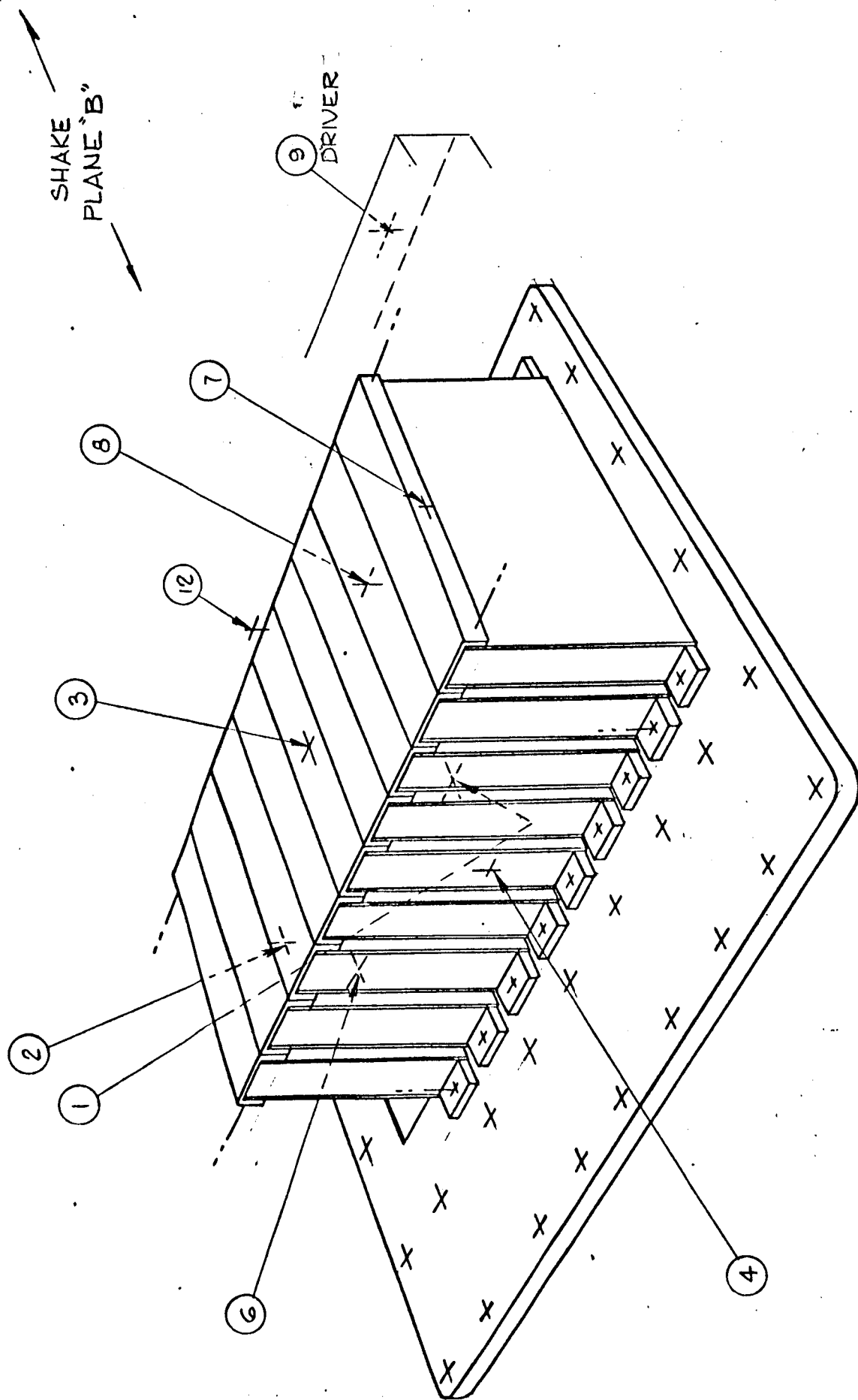


FIGURE A-4
AROD V.B
"B" PLANE SHAKE

NOTE: Detail construction of the connector holders at the top of each subassembly has been simplified over that used of the units under test. It is felt however, that the effects on the test results will be negligible.

The nine subassemblies were installed on the chassis base plate, torqued to specification and bolted together with thru tension bolts. The complete assembly was then bolted to a shake fixture known to be free of resonances in the test range. Figures 2, 3 and 4, picture the test set up and designates the referenced shake axis.

All tests were conducted using a Ling 275 shake table driven by a Ling R-1003 sinusoid console. Data was recorded using an 11 channel CEC as recording oscillograph. Input to the table was held to 5 g or .10 inch double displacement whichever was limiting. Scanning rate, from 5 to 2000 cycles was at 1 octave per minute. Table I lists the individual tests run. Raw data for the tests appears in figures 6 through 14.

TABLE I

<u>Test</u>	<u>Tapes</u>	<u>Axis</u>	<u>Excursion</u>	<u>g</u>	<u>Figure</u>	<u>Remarks</u>
1	-	C		5		Visual Search 40-2000 60 cps
2	10528	C	.10 in	5	2	5 - 2 KC Recorded
3	10529	C	.10 in	5	2	5 - 2 KC Attenuation corrected record run - aborted
4	10530	A	.10 in	5	3	5 - 500 cps (10" span) Recorded
5	10531	A	.10 in	5	3	5 - 500 cps (8" span) Recorded
6	-	A		5		500 - 2 KC Attenuation set
7	10532	A		5	3	500 - 2 KC (8" span) Recorded

Table I (Con't.)

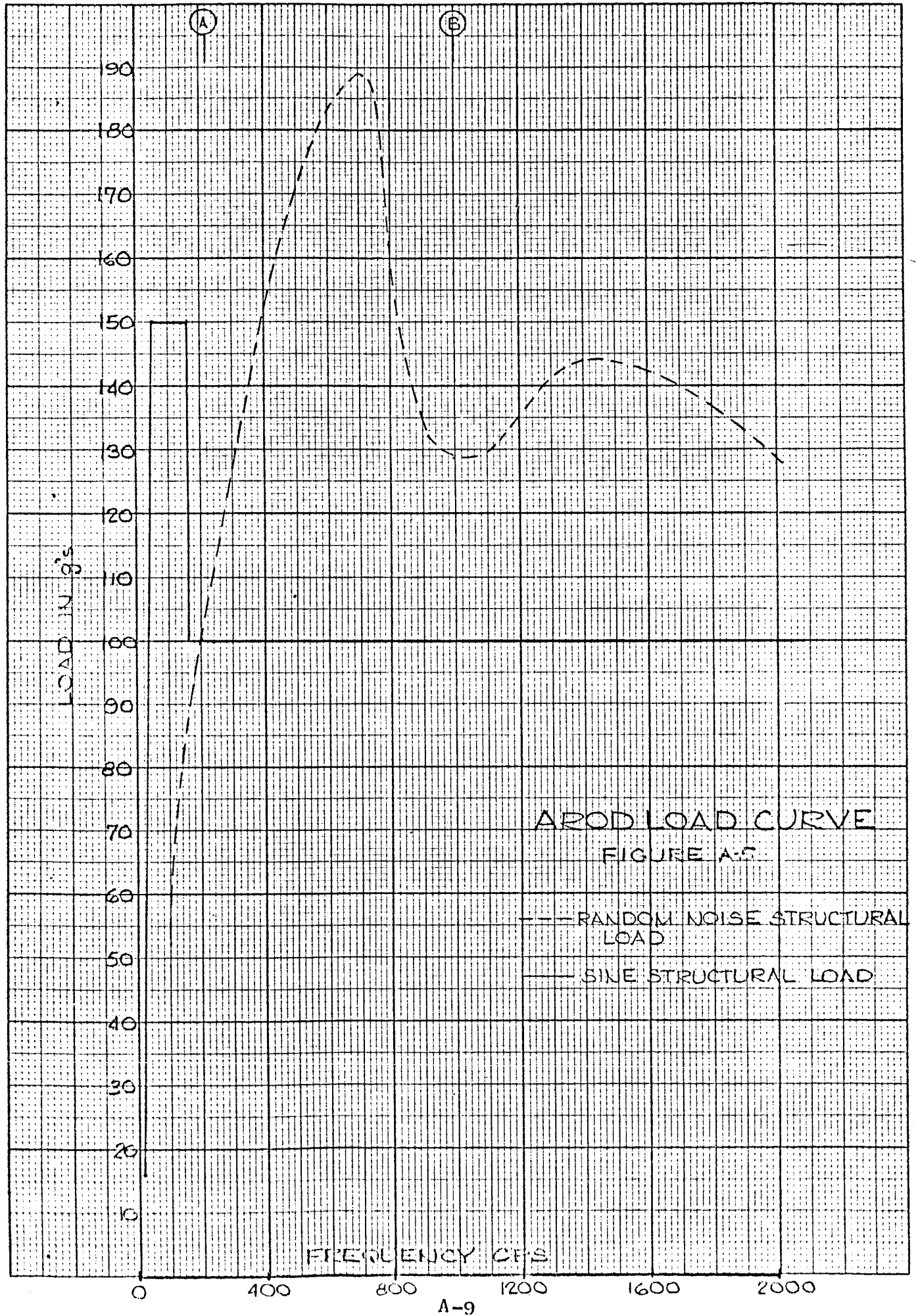
<u>Test</u>	<u>Tapes</u>	<u>Axis</u>	<u>Excursion</u>	<u>g</u>	<u>Figure</u>	<u>Remarks</u>
8	10533	A		5	3	500 - 2 KC (10" span) Recorded aborted
9	10534	A		5	3	500 - 2KC (10" span) Recorded
10	-	B	.10 in	5		5 - 500 cps Attenuators set
11	10535	B	.10 in	5	4	5 - 500 cps (10" span) Recorded
12	10536	B	.10 in	3	4	5 - 500 cps (8" span) Recorded
13	-	B		5		500 - 2 KC Attenuator set
14	10537	B		5	4	500 - 2 KC (8" span) Recorded
15	10538	B		5	4	500 - 2 KC (10" span) Recorded

Figure 5 is a reproduction of the load curves derived from the AROD sine and random noise environmental spec. section V attachment A of the contract specification, superimposed on one another. For each of the two curves a transmissibility of 10 has been assumed. The random curve shown is a plot of the maximum g levels expected. They are the "peak" or 3 sigma values. It can be concluded from these curves that components in the AROD system will be subjected to a minimum g loading if the supporting structure has a resonance between 165 cps and 300 cps or above 850 cps.

Points A and B at the top of figure 5 indicate the two points of resonance determined by actual search. Transmissibility was well under that assumed in deriving the curves. Other points of resonance were noted, but in each case nonstructural supporting members such as the center of the base plate, were involved. These are not considered as detrimental to the equipment.

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NO. 340 20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH



CONCLUSIONS

The packaging concept as tested minimizes the vibration input to the electronic component. It should be possible to duplicate the test results in the final AROD configuration.

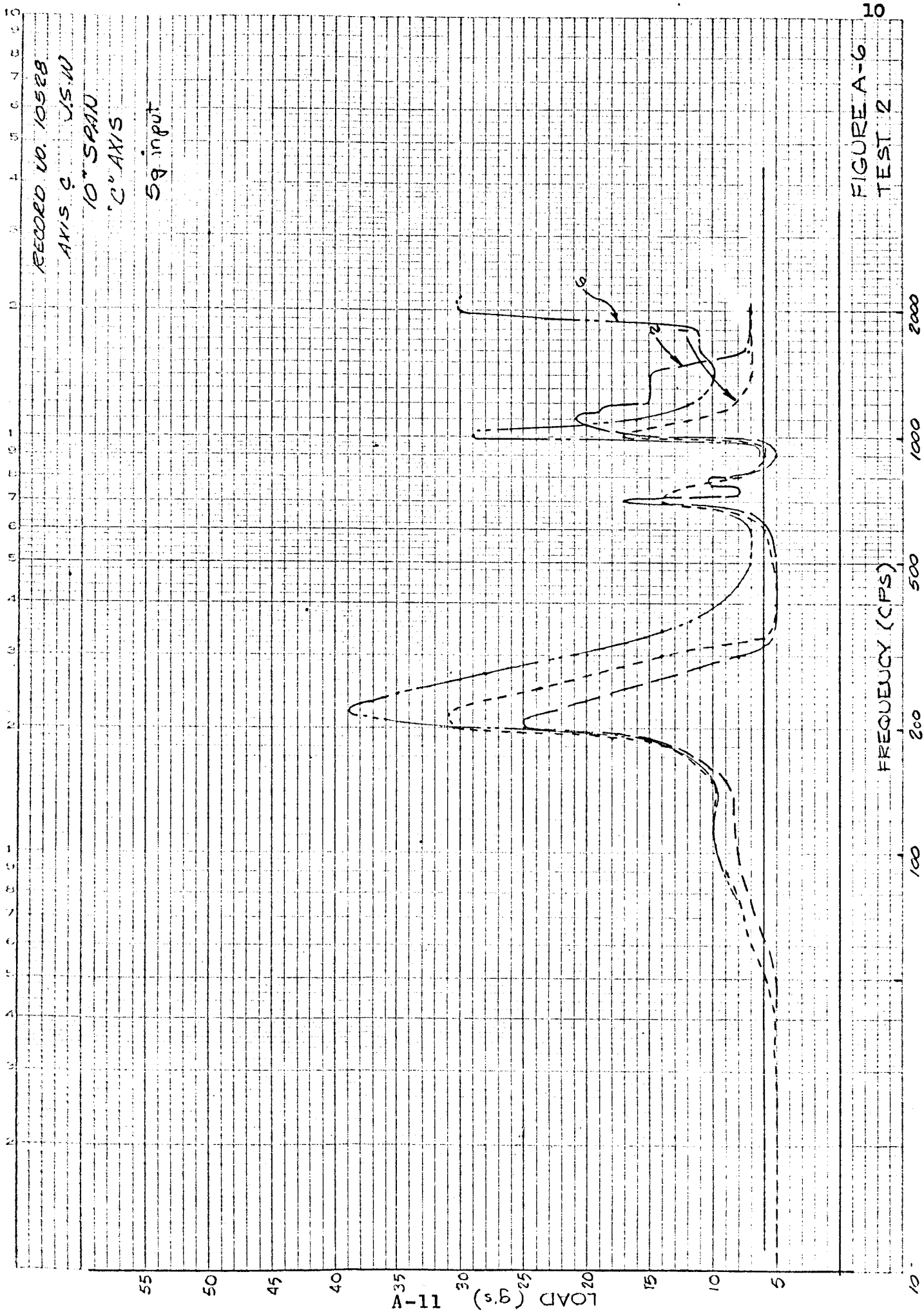
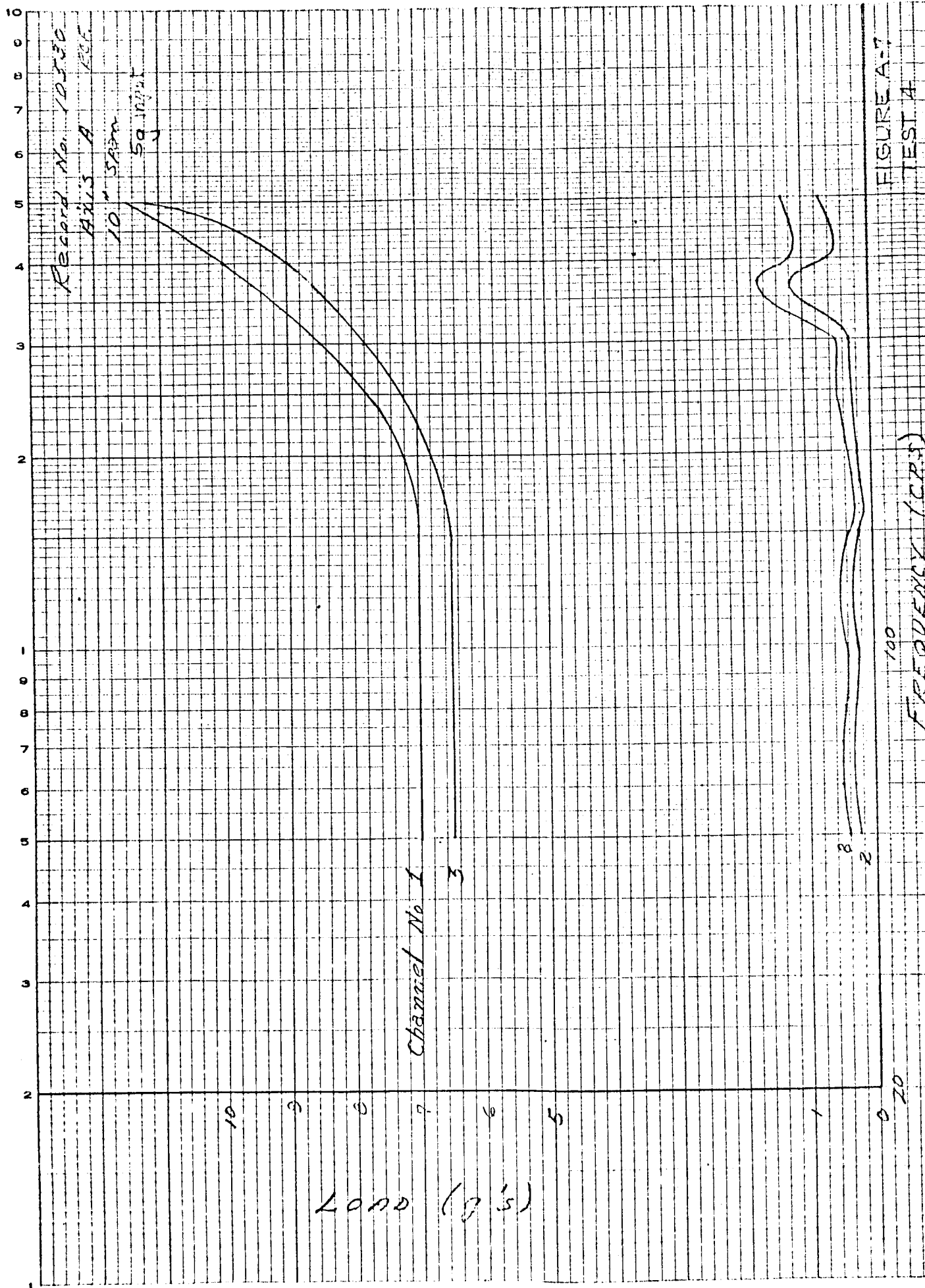
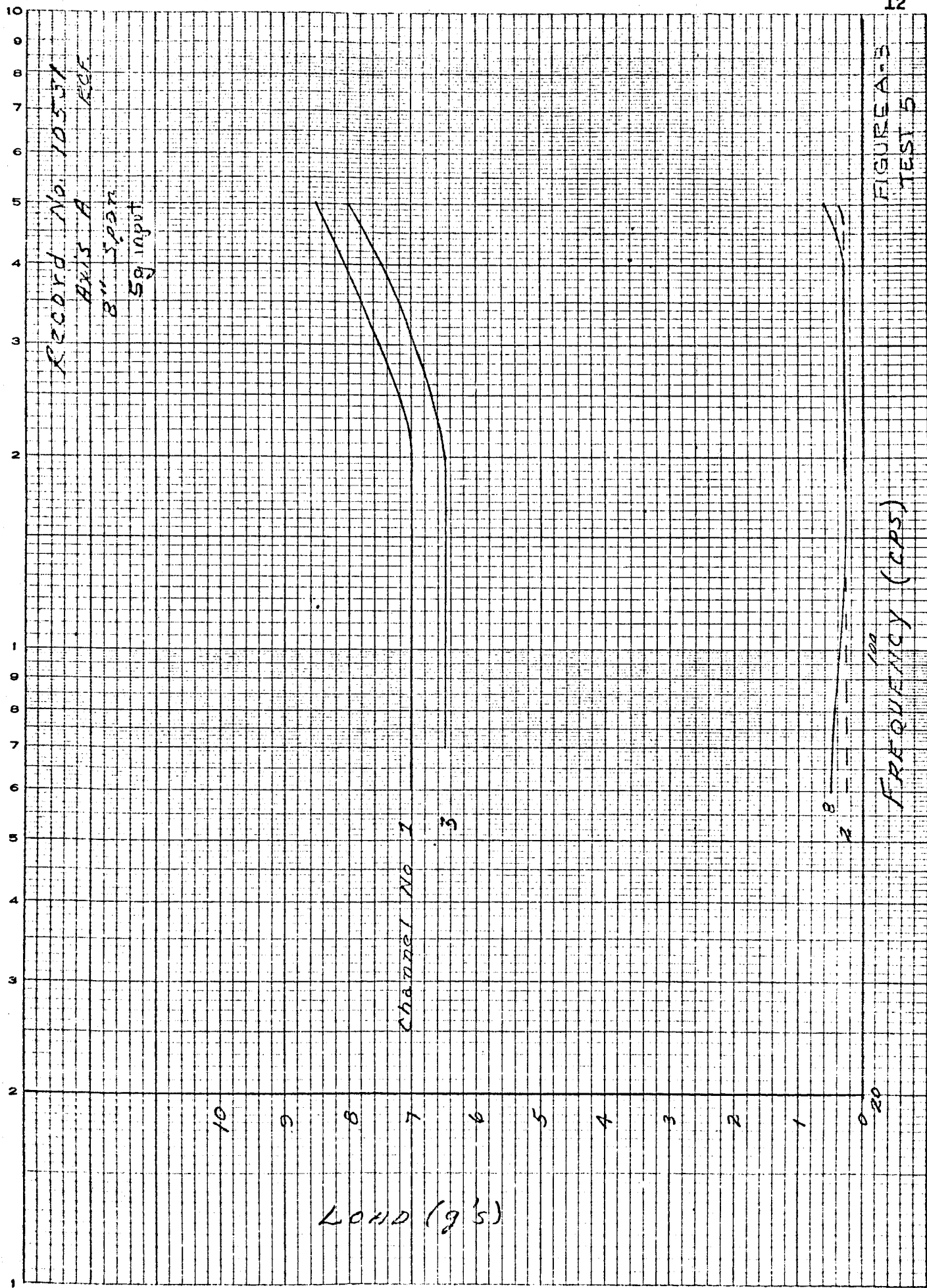


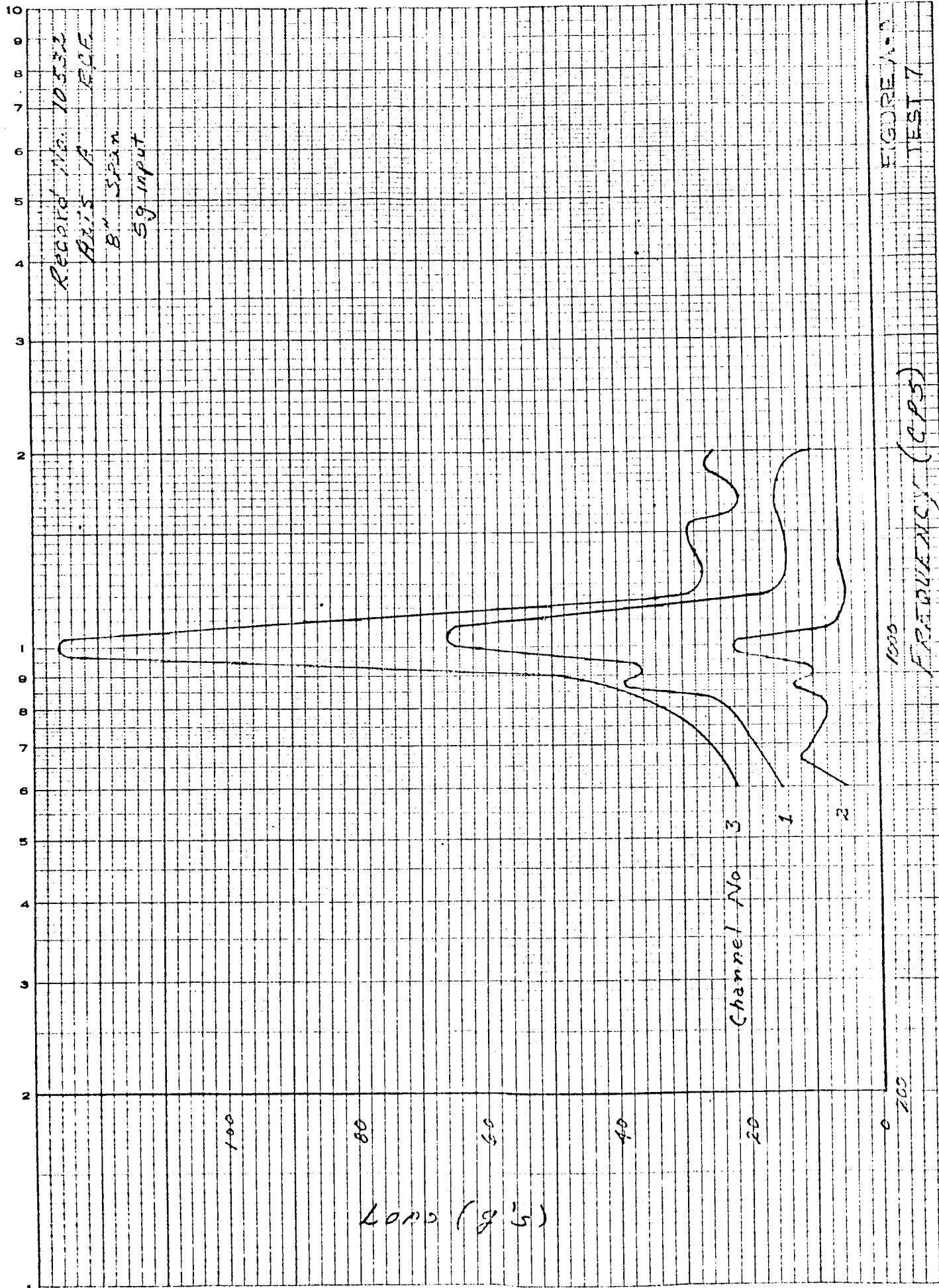
FIGURE A-6
 TEST 2

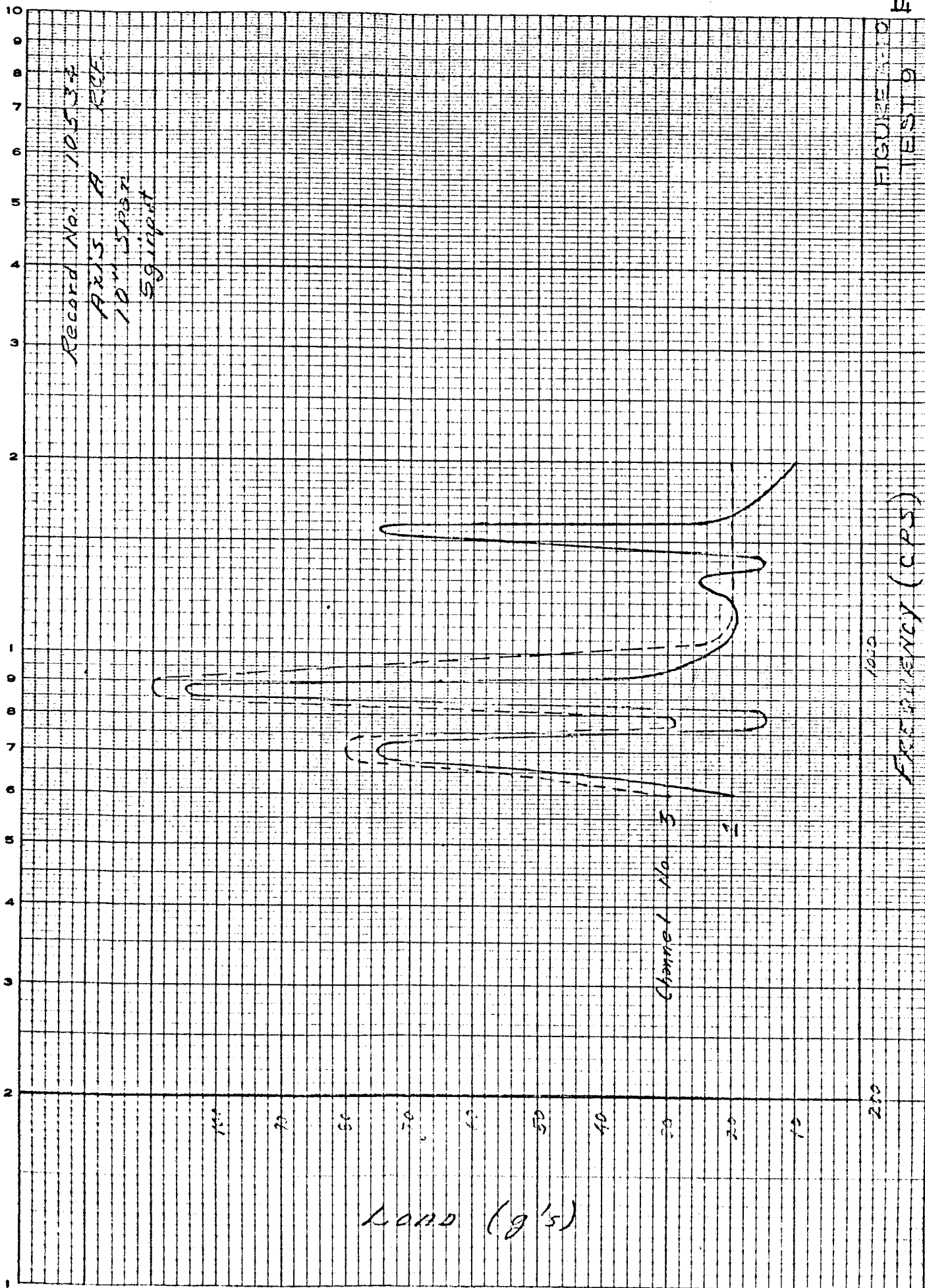


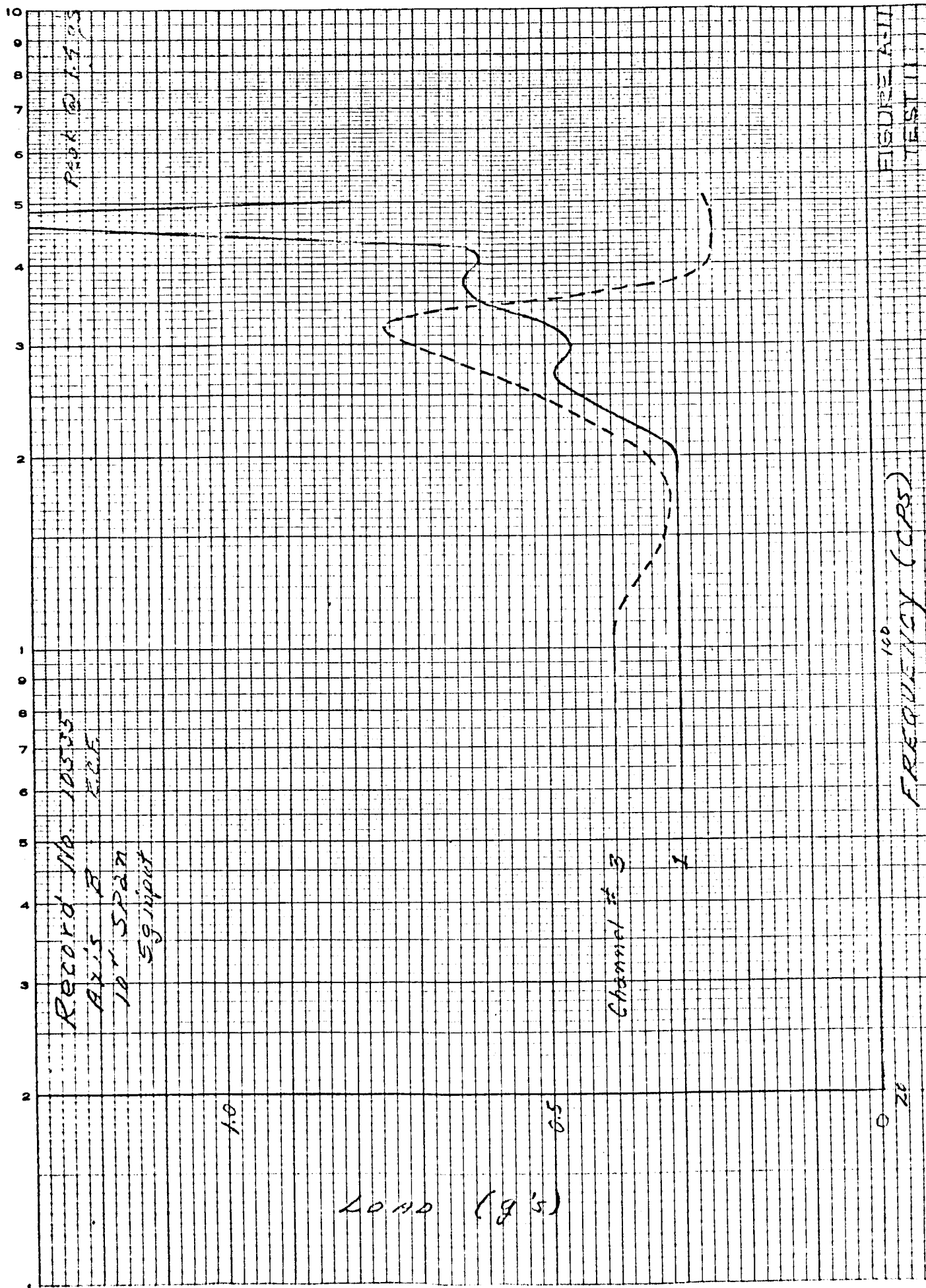
3400 DIELECTRIC GRA... PER...
SEMI-LOG GRAPHIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE A-5
TEST 5









NO. 340-L210 DIETZEN GRAPH PAPER
1-10 MIC
2 CYCLES X 10 DIVISIONS PER INCH



FIGURE 1
TEST 12

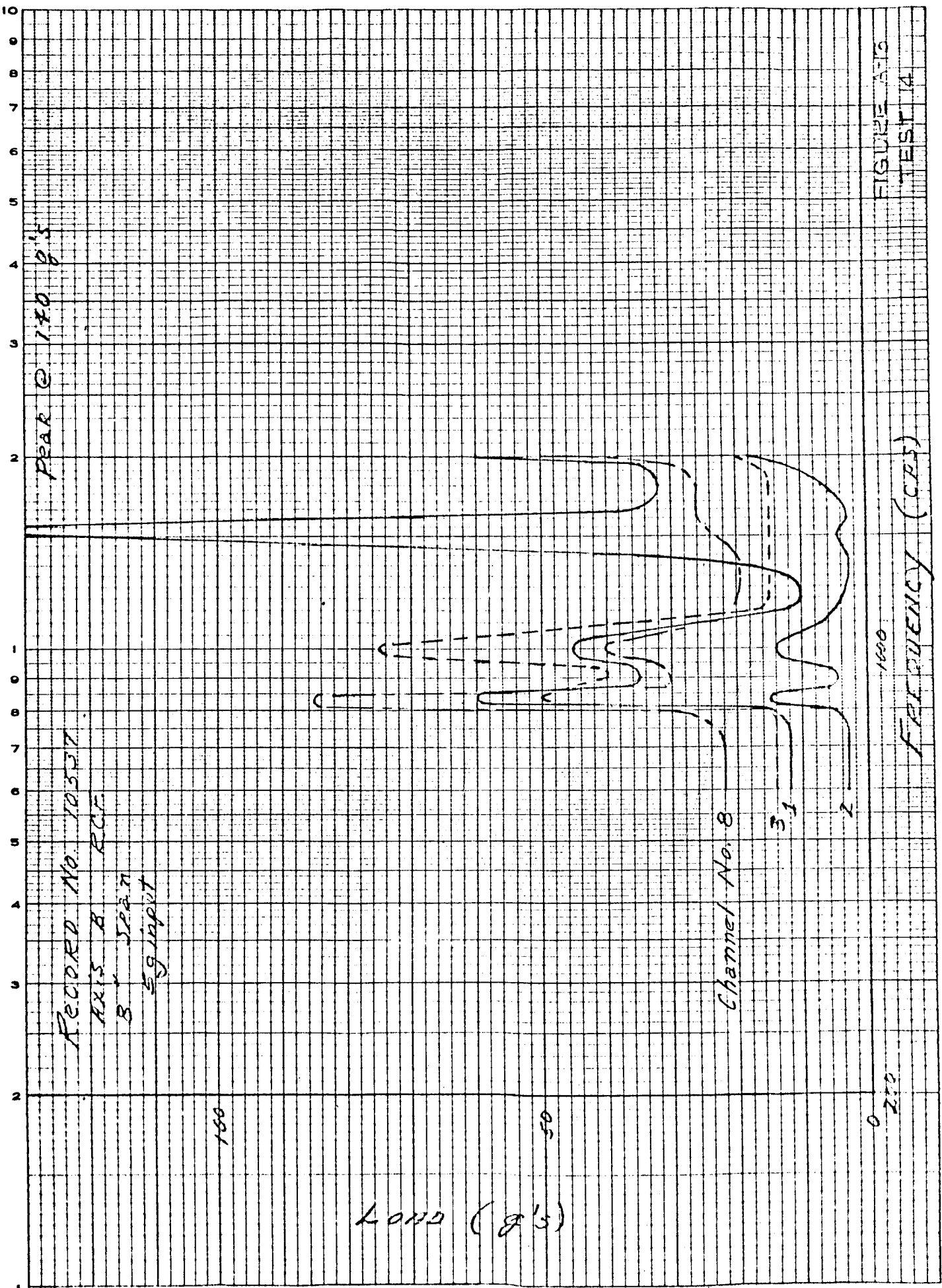
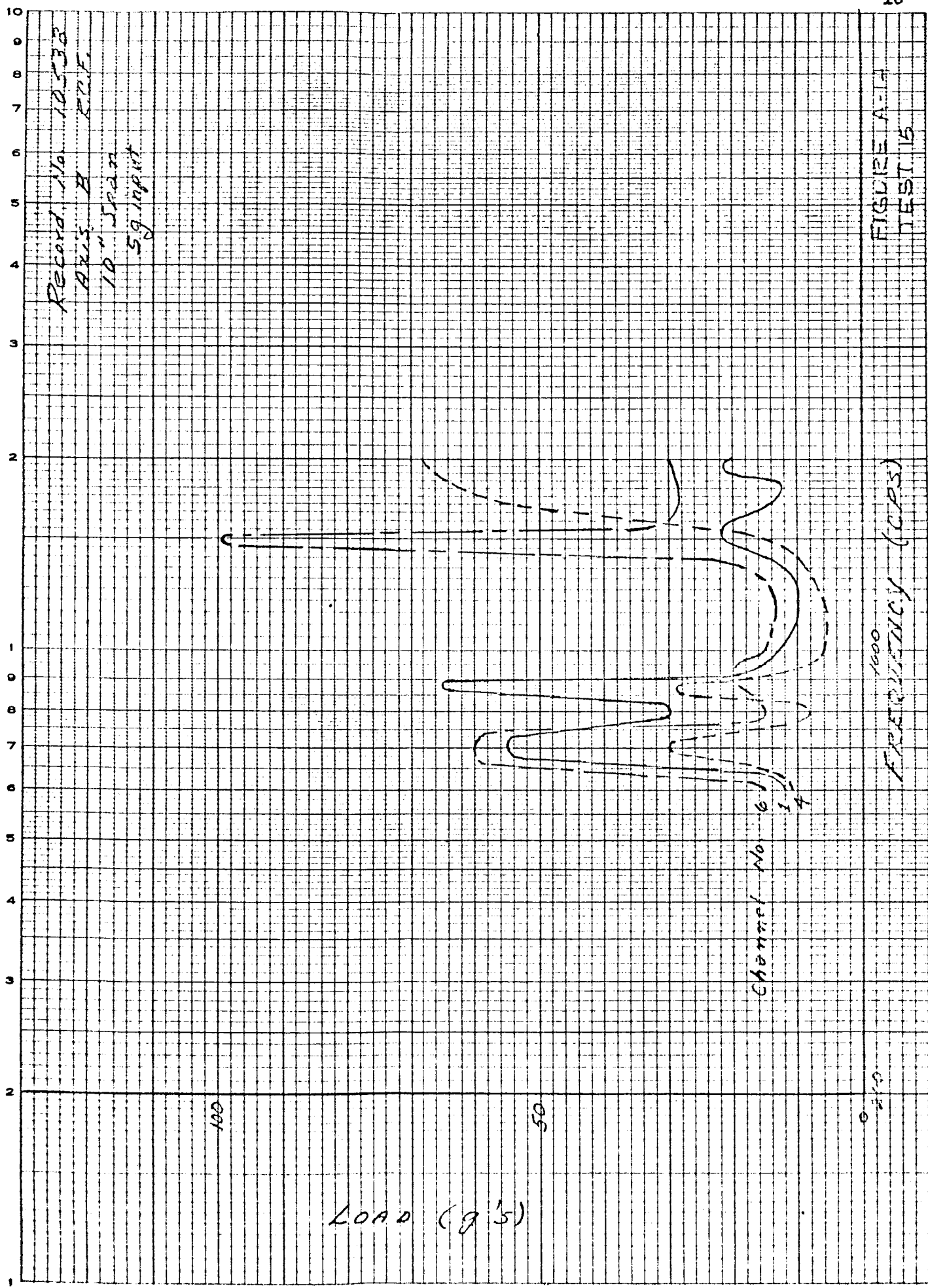


FIGURE A-13
TEST 14



APPENDIX B

PRESSURE TEST OF AROD BASE PLATE

PURPOSE

To determine the deflection, due to pressurization of the newly designed lightweight base plate proposed for the AROD package.

SCOPE

Deflection tests were restricted to the effects of pressurization only. Excursions that are the result of vibratory inputs to the system are treated separately and not included as part of this test. The peak deflections resulting from the two load conditions, are not additive since the peak vibration loads occur during launch at atmospheric pressure while the peak internal pressure occurs in orbit.

TEST EQUIPMENT

AROD Test Fixture

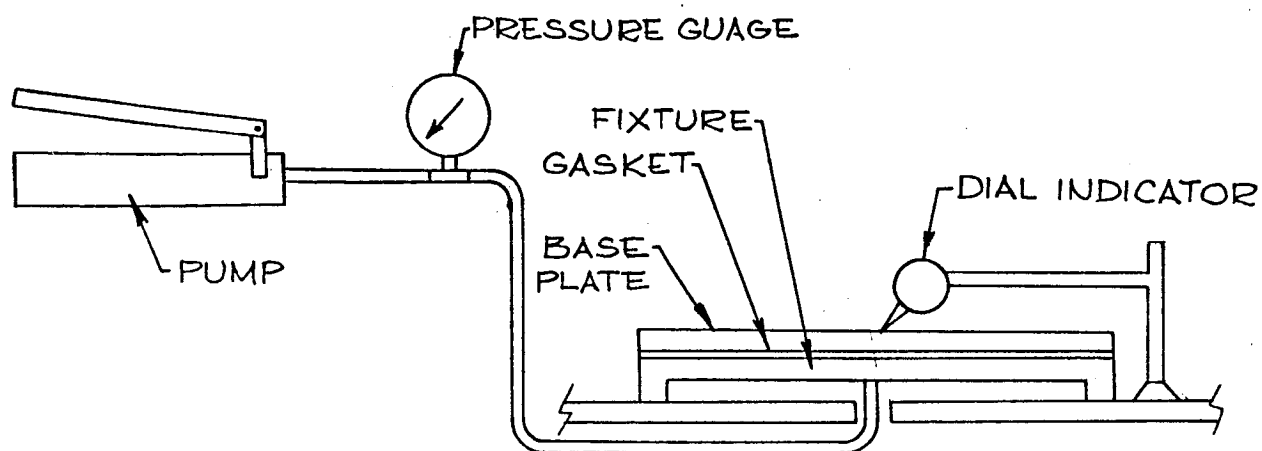
Ashcroft - 0-300# Hydraulic Gauge

Hydraulic Hand Pump Blackhawk Model P-76

Dial Indicator Starrett #711G

PROCEDURE

Test set up was as shown in figure 1. Oil rather than air was selected for the test simply as a safety measure. Measurements of deflection versus pressure were taken over the range of 0 to 30 PSIG. This data is shown on the graph in figure 2.



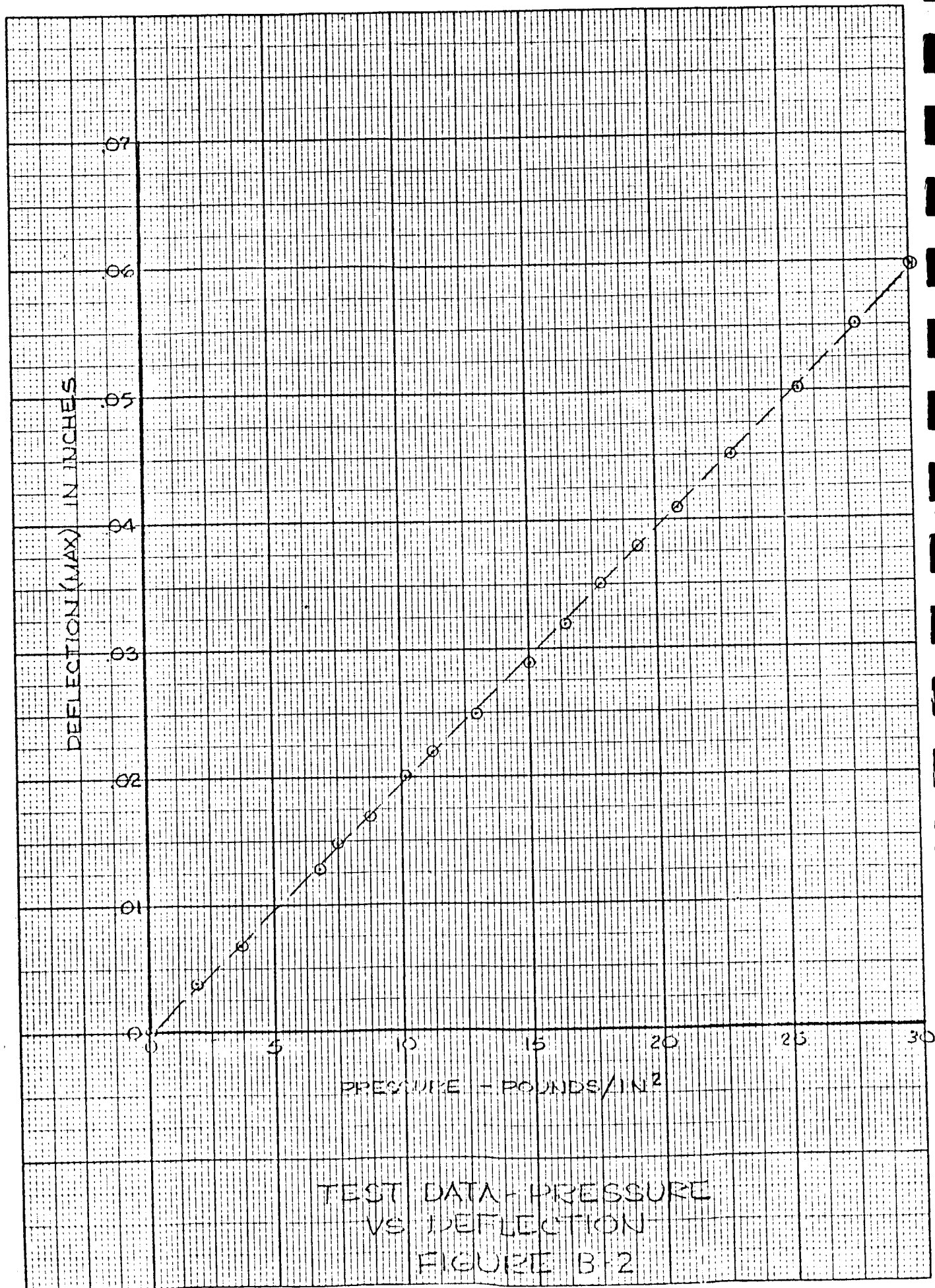
TEST SET-UP
FIGURE B-1

SUMMATION

The detail analysis of the selected base plate section appears in referenced document MELR-AROD Structure Report No. WM 3065-11-1. The predicted deflection at 30 PSIG was .052 with an actual measured deflection of .060 inches.

CONCLUSION

The cross section is performing approximately as expected, though there is an obvious area of uncertainty associated with the end conditions of the beam.



APPENDIX C

RESULTS OF THERMAL MOCK-UP TESTS

FOR THE

VEHICLE-BORNE AROD UNIT

INTRODUCTION

This memo documents the results of the thermal tests to determine the temperature profile within the vehicle-borne AROD equipment. This equipment contains a large number of flat packs, all of which are assembled in modules. A picture of an unpotted module is shown in Figure 1. This figure shows the general mechanical arrangement of the flat-pack within the module. Figure 2 shows the module configuration after potting. A subassembly is constructed with modules in the form shown in Figures 3 and 4. Seventeen modules are contained in each subassembly and are soldered to one of the two subassembly printed circuit boards.

In an actual equipment several subassemblies are mounted side by side to form the total equipment. This equipment in the air vehicle is mounted to a thermal conditioning panel which never exceeds 27C and functions as a thermal sink for the AROD equipment.

TEST PROCEDURE

MODULE

The first thermal test series was performed to determine the module flat pack to module surface thermal resistance. This test was implemented by attaching thermocouples to the flat pack and module surfaces and measuring the temperature rise per watt of individual flat pack power dissipation. All twenty individual flat pack circuits were identical and connected in parallel so that each flat pack dissipated equal power. The actual module used in these tests is shown in Figures 1 and 2.

SUBASSEMBLY

The project supplied a subassembly mock up for the thermal tests. This mock up was similar to an actual subassembly except that to simplify construction the active module components, the flat packs, were replaced by four resistors in each module. The previously noted module test supplied the actual module internal

temperature data and therefore the use of flat packs in the subassembly modules was not necessary.

This subassembly was instrumented with several thermocouples to provide an adequate temperature profile. The locations of these thermocouples is shown in Figures 3 and 4 and the temperatures corresponding to these points are listed on the attached test data sheet.

Figure 5 shows a sketch of the actual subassembly mock up test setup. Guard heaters were installed opposite the test subassembly faces and were regulated to provide equal temperatures on the center of the guard heater plate faces and the AROD subassembly board center faces. This situation simulates the placing of other operating AROD subassemblies on each side of the test subassembly.

In addition to providing the thermal data for the standard module construction, further tests were conducted to simulate the effect of inserting an aluminum thermal sink strip between two flat pack rows within the modules. This was simulated by placing 3 inch long by 0.55 inch wide by 0.02 inch thick aluminum strips between each module face. In a thermal sense, the placing of the aluminum strips between modules duplicates the placement of the strip within the modules.

DISCUSSION

The highest temperature component (flat pack) junction will be found in the center module of the center subassembly. Denoting this situation as the thermal "worst case" design condition; a thermal path from this component junction to the equipment sink, the thermal conditioning panel, can be constructed. The total thermal path is illustrated in Figure 6. This thermal path can be subdivided into the temperature rise of the equipment case bottom plate over the thermal conditioning panel, the module surface rise over the equipment case bottom, the flat pack case rise over the module surface, and the flat pack junction rise over the flat pack case surface.

An analysis of the equipment case bottom to air vehicle thermal conditioning panel thermal resistance shows that its value is 0.005 C/watt of equipment dissipation. With a maximum equipment dissipation of 40 watts, this rise is 0.20 C. The rise of the module surface over the equipment case bottom plate is plotted versus subassembly power dissipation in Figure 7. As an example of this rise, assume that the subassembly dissipates 3.4 watts (.2 watts per module) this rise is 39C for the standard type module and 28C for the module with the aluminum strip. The flat pack surface to module surface thermal resistance was found to be 25 C/watt. With each of the twenty flat packs in the module dissipating, say typically 0.01 watts (.2 watts/module), the flat pack to module surface temperature rise is 25 C/watt x .01 watts = 0.25 C. The last path temperature rise is from the flat pack junction to the flat pack surface. A worst case thermal resistance for this path is 150 C/watt. At 0.01 watts, this corresponds to a rise of 1.5 C.

For the particular example stated, the total temperature rise from the flat pack junction to the vehicle conditioning panel is:

$$\begin{aligned} \text{Total Temperature Rise (Standard Module)} &= .25 \text{ C} + 39 \text{ C} + \\ &1.5 \text{ C} = 40.75 \text{ C} \end{aligned}$$

$$\begin{aligned} \text{Total Temperature Rise (Module's with an Aluminum Strip)} &= \\ .25 \text{ C} + 28 \text{ C} + 1.5 \text{ C} &= 29.75 \text{ C} \end{aligned}$$

With a 27 C vehical conditioning panel, the hottest flat pack junction temperature will be:

$$\begin{aligned} \text{Flatpack Junction Temperature (Standard Module)} &= \\ 27 \text{ C} + 40.75 \text{ C} &= 67.75 \text{ C} \end{aligned}$$

$$\begin{aligned} \text{Flatpack Junction Temperature (Modules with an Aluminum Strip)} &= \\ 27 \text{ C} + 29.75 \text{ C} &= 56.75 \text{ C} \end{aligned}$$

Thus both module types will have worst case junction temperatures below the projects specified maximum allowable value of 85 C.

CONCLUSION

The thermal mock up tests have provided general AROD thermal design information. The project must determine which module construction is to be used in the AROD since the final decisions on subassembly power, module cost, unit weight, etc., rest with the project.

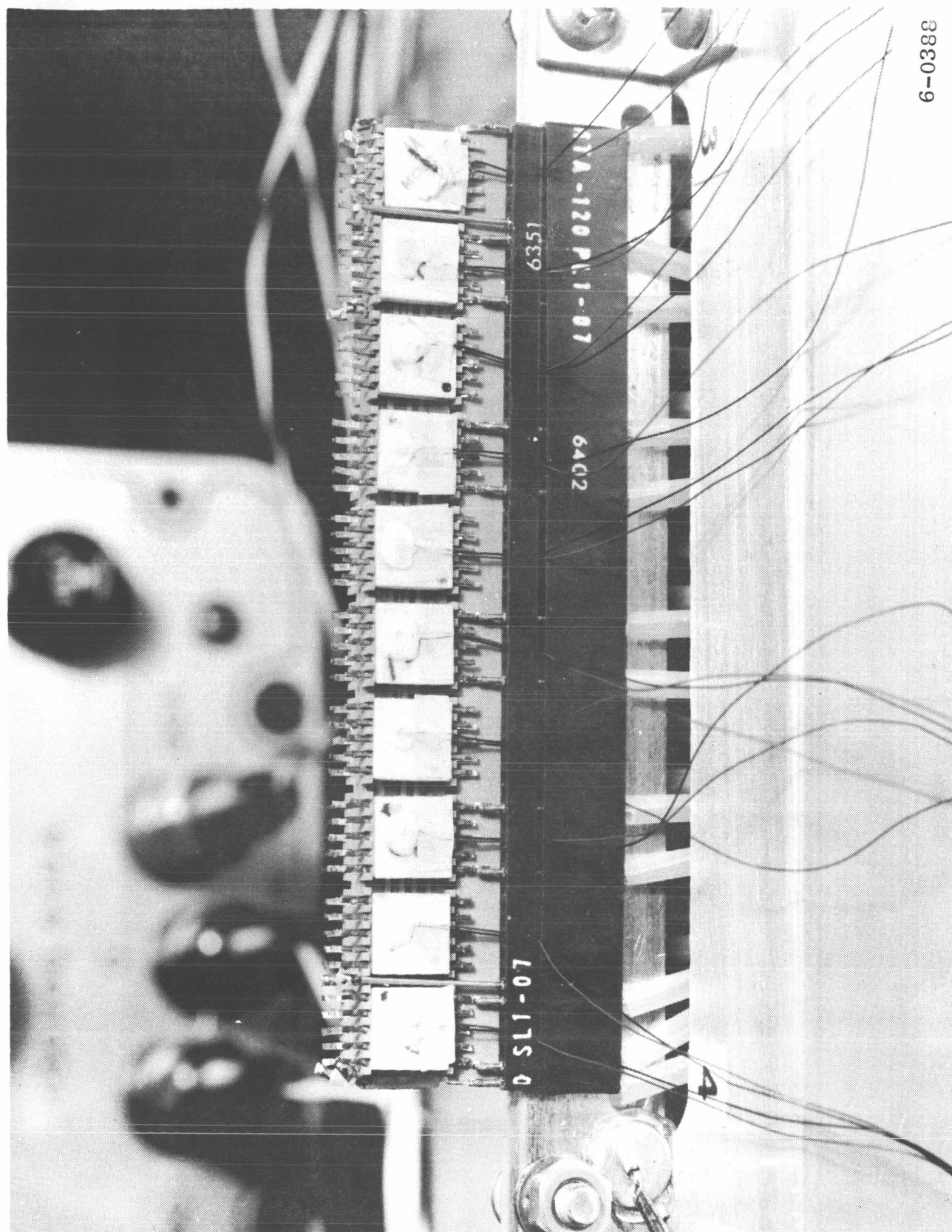
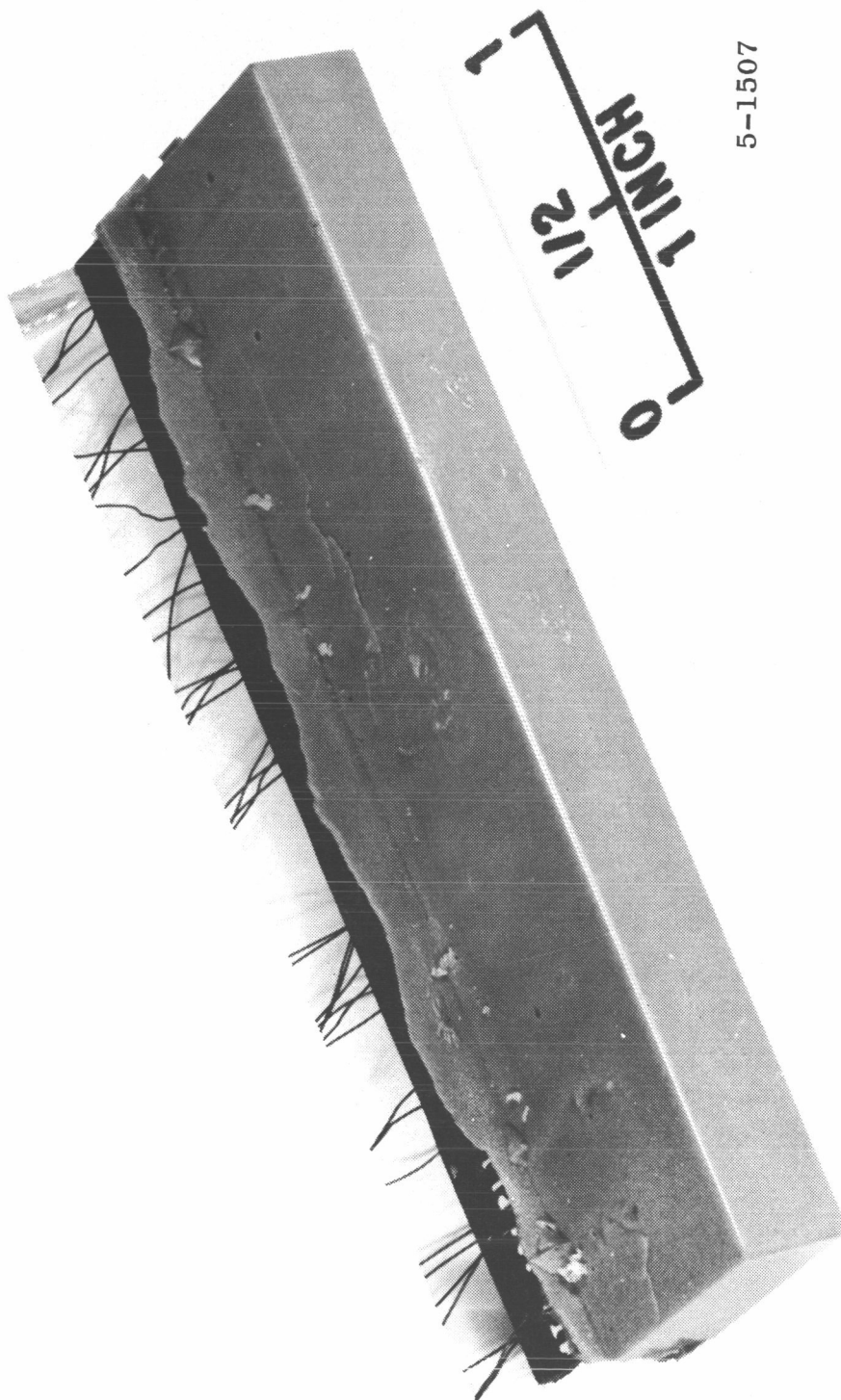


Figure C-1. AROD Module (Before Potting)

6-0388



5-1507

Figure C-2. AROD Module Mock-up (Potted)

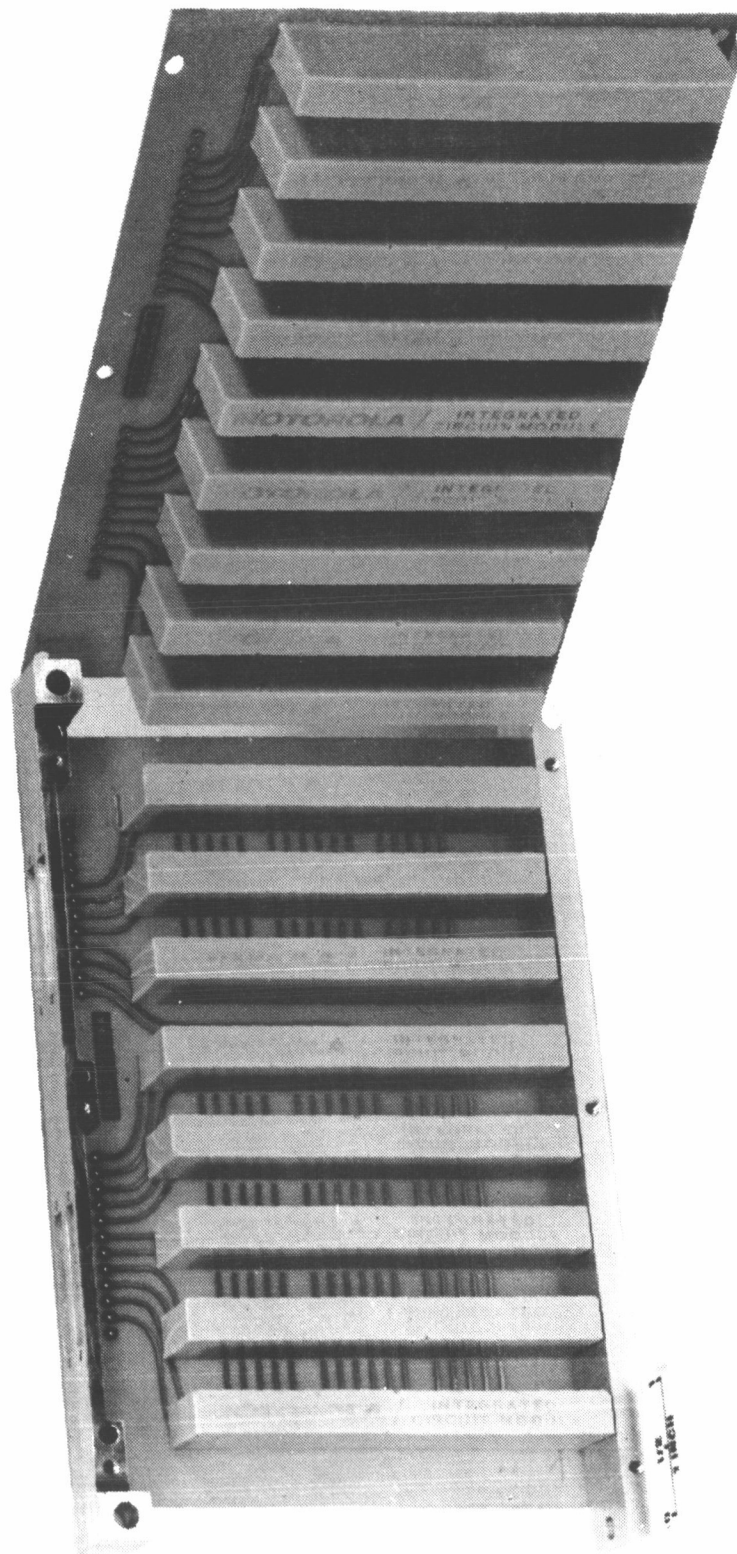


Figure C-3. AROD Assembly, Opened

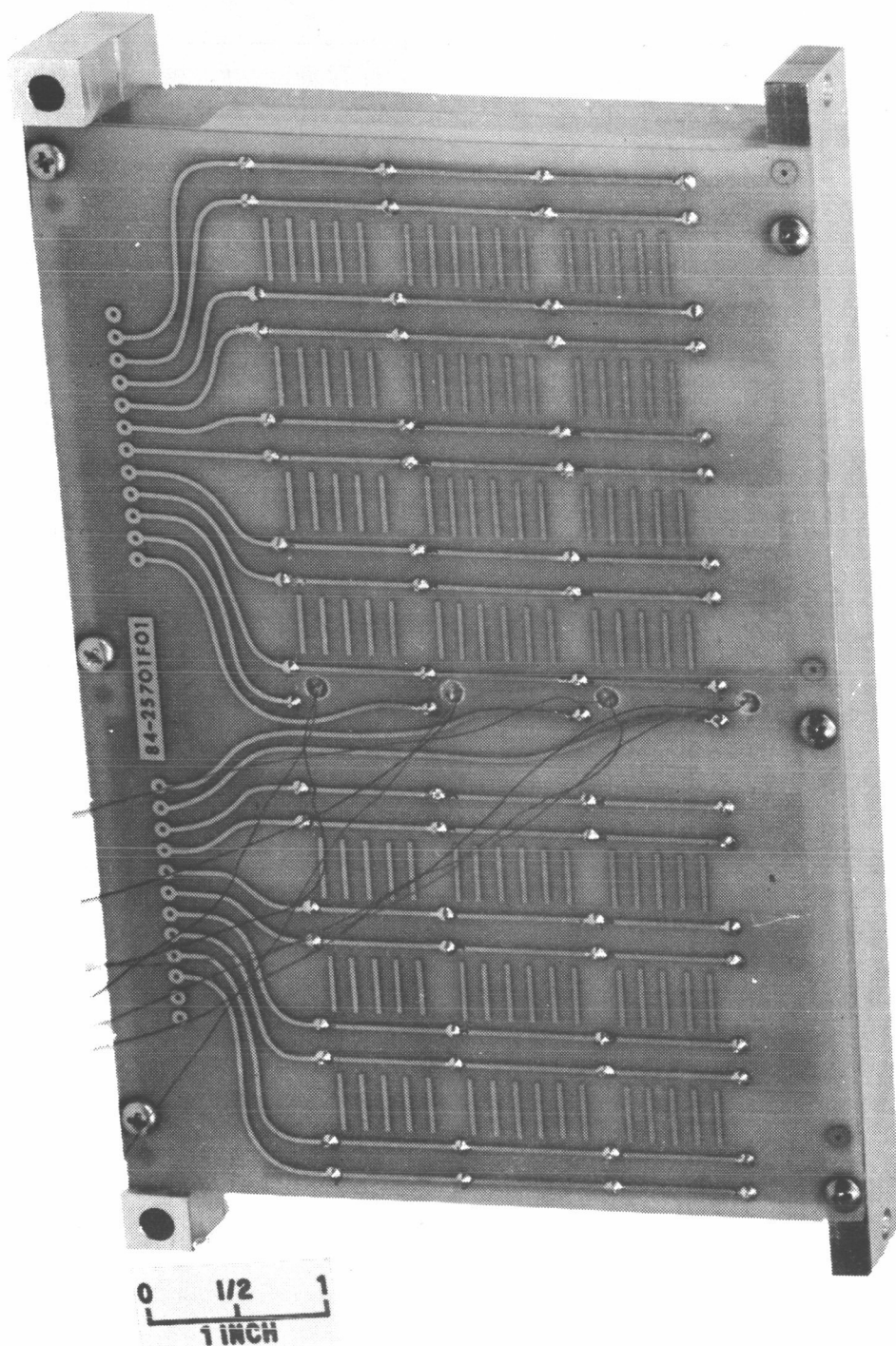
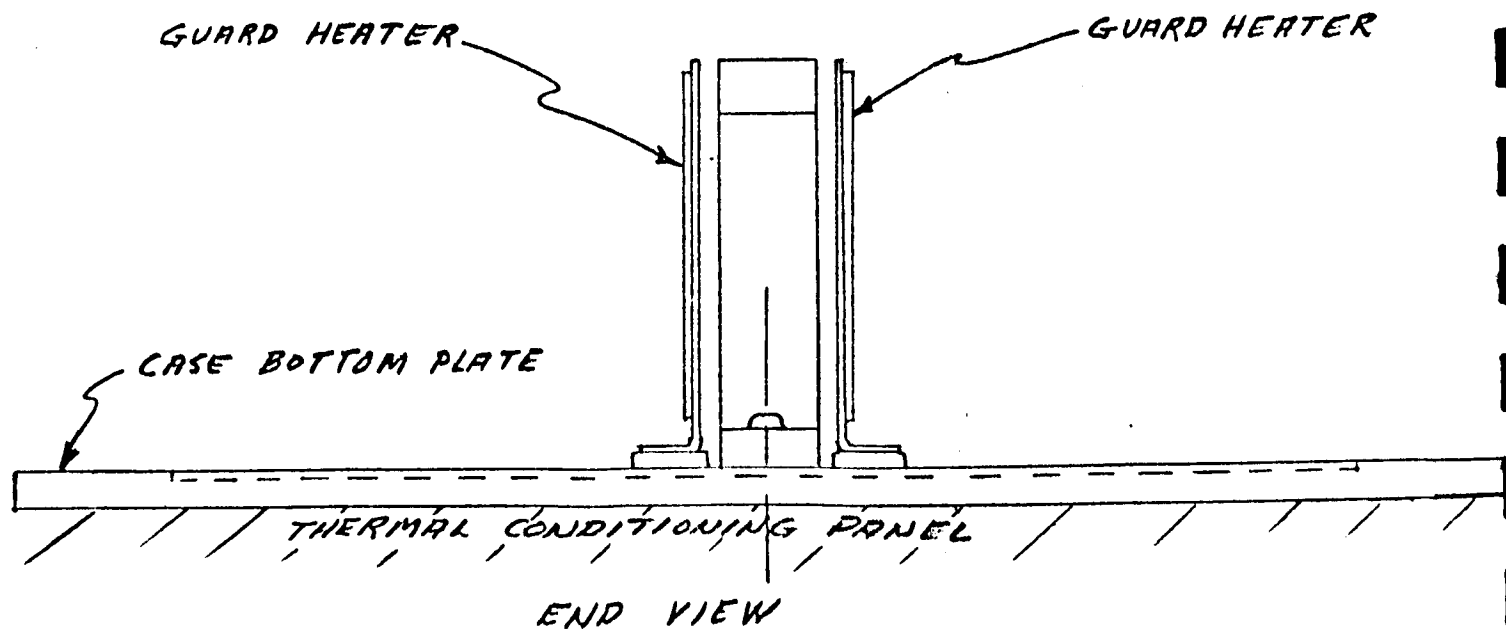
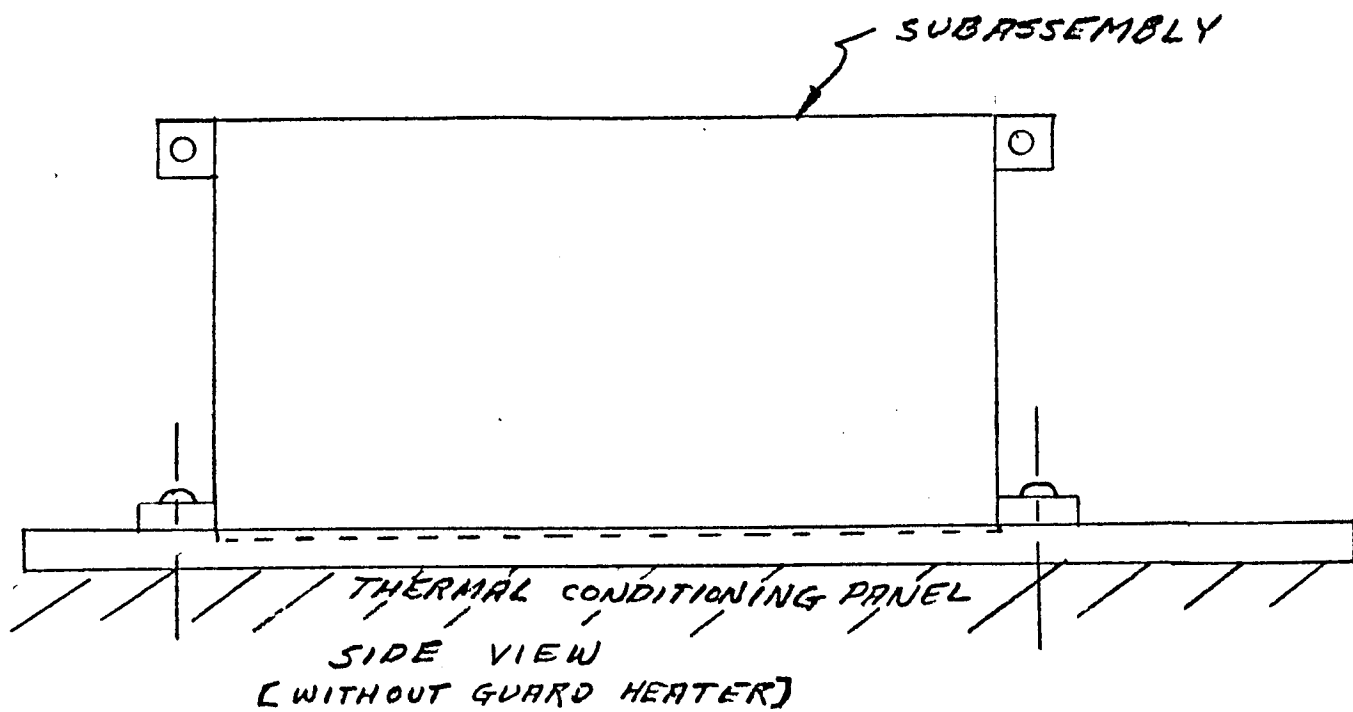


Figure C-4. AROD Subassembly (With Thermocouple Locations)

FIGURE C-5

AROD THERMAL TEST SET UP



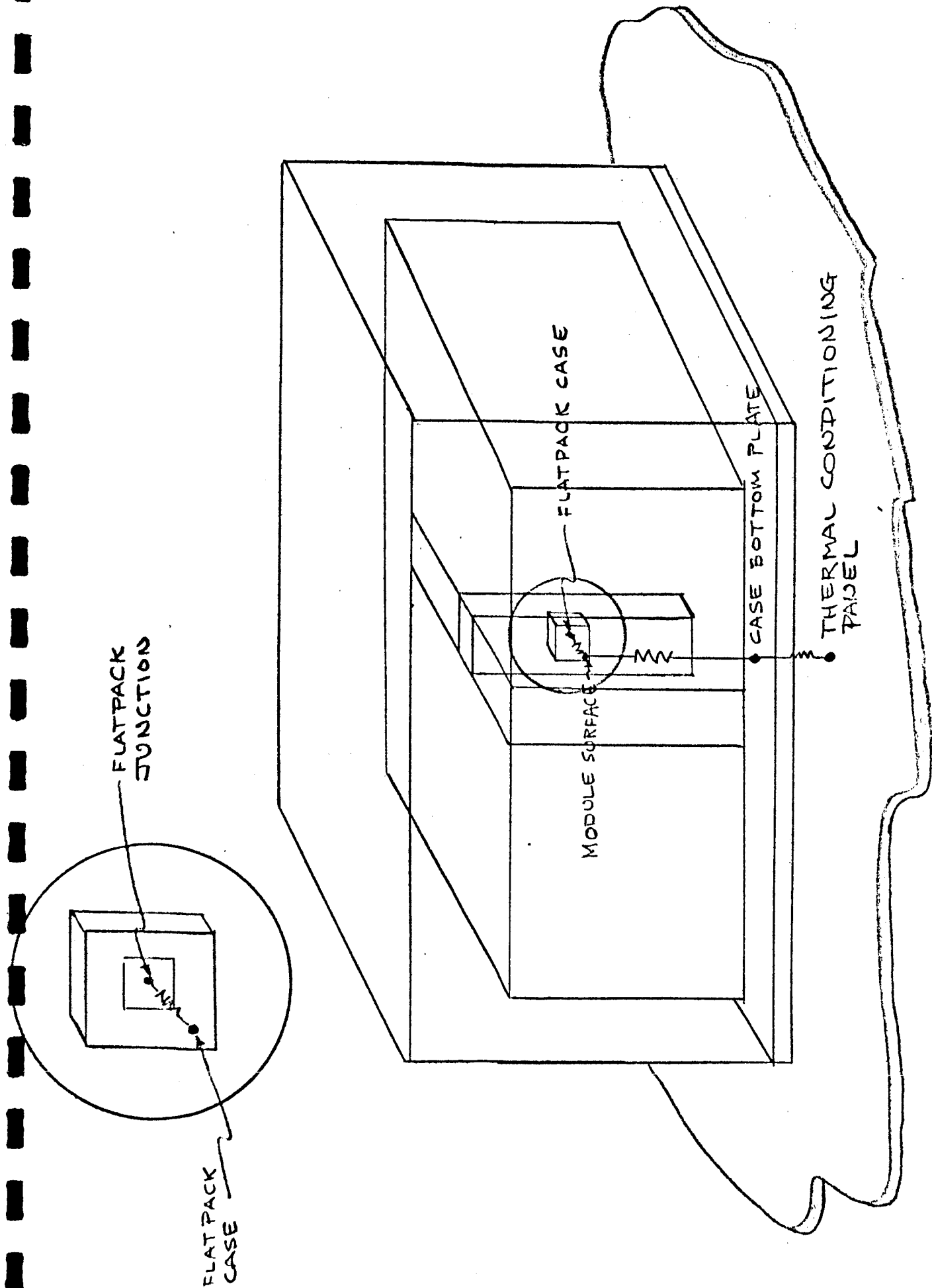
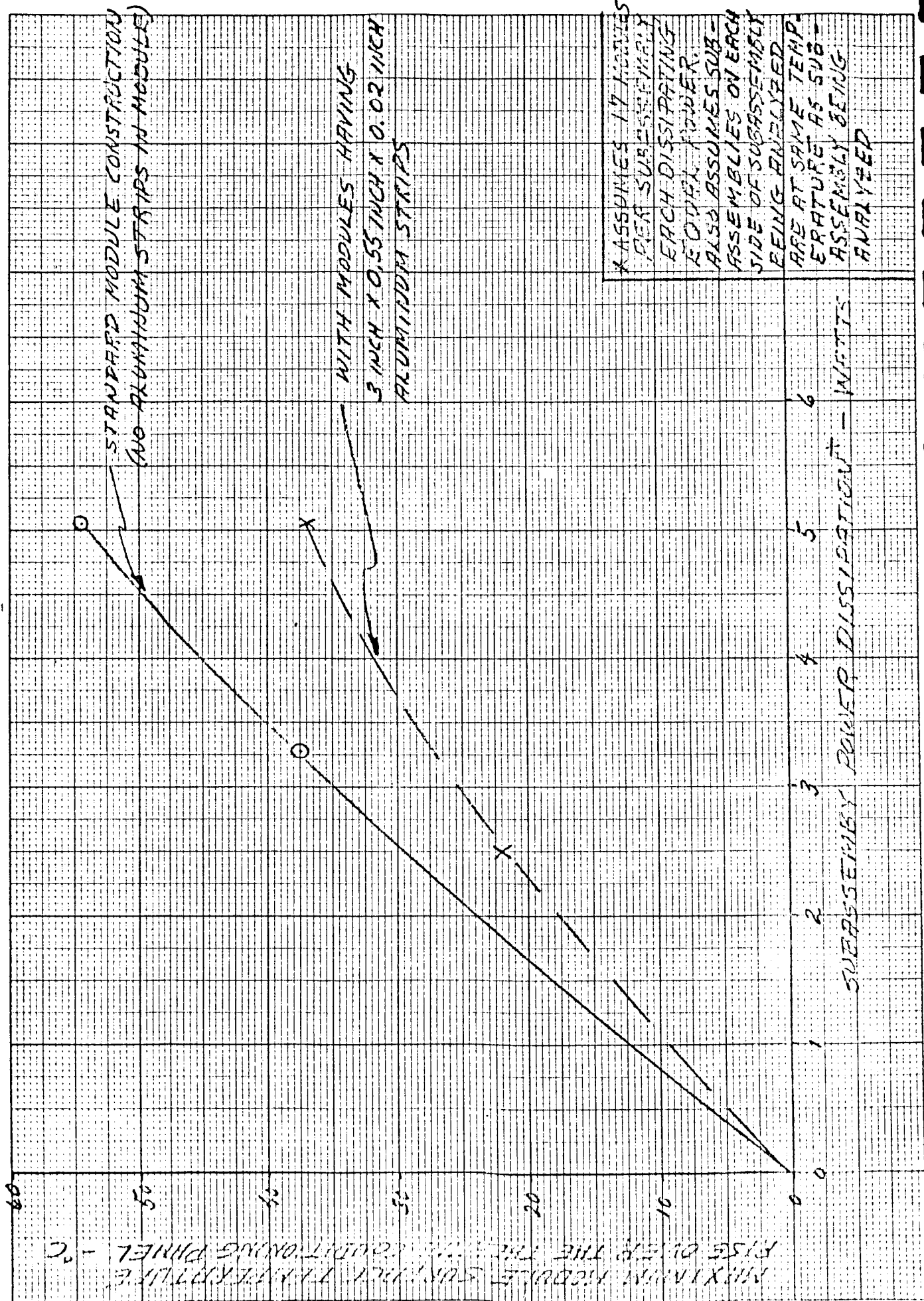


FIGURE 66 FLATPACK JUNCTION TO AIR VEHICLE THERMAL
CONDITIONING PANEL THERMAL PATH

FIGURE 7



APPENDIX D

THERMAL TEST OF A TYPICAL AROD
CORDWOOD MODULE

THERMAL TEST OF A TYPICAL AROD CORDWOOD MODULE

A thermal test was made on a cordwood module that is typical of those used in the AROD equipment. The mockup that was tested was a foam/epoxy module which contained resistors and transistors to thermally simulate an actual module. Essentially, all the heat dissipated in the module was uniformly distributed among three 2N1613 transistors. Thermal instrumentation of the module was accomplished by soldering 40 gauge copper constantan thermocouples to the case of each of the 2N1613 transistors and to one non-dissipating component. A cross-section of the module and the electrical wiring schematic are shown in Figure 1.

In order to simulate the actual mounting of the module, a 0.03" thick "L" shaped bracket was bonded to the top of the module with GE 585 pressure sensitive adhesive. This bracket was then bonded to a heat sink with DC 140 silastic adhesive. Additional thermocouples were bonded to the bracket and to the sink so the internal component temperature could be referenced to these locations (see Figure 1).

Three different test series were made on the module. These tests consisted of (1) a room bench test, (2) a room bench test with three inches of fiberglass wrapped around the module and (3) a vacuum test at 1×10^{-5} mm Hg. Because an array of modules will be sandwiched together and the package will be sealed during actual operation, test (2) above more closely represents the environmental condition to which the modules will be exposed. The results of the tests are shown in Figures 2 through 4.

Because the sink-to-base thermal resistance of the test apparatus was not representative of that in the actual package, it was decided to use the base of the "L" bracket as the reference point and adjust the values shown in Figures 2 through 4 for the actual mounting conditions. Review of the present design indicates that a thermal resistance value of approximately 1.0 C-SQ IN/WATT can be expected at the base-sink interface.

Furthermore, if a contact area of 0.3 SQ IN (approximate module cross-section area) is assumed, the thermal resistance value becomes 3.33 C/WATT. This means, for example, that for a module dissipation of 450 MW, the values shown in Figures 2 and 3 should be increased by approximately 1.5C.

It was learned from project personnel that the transistors used in this test simulate MC 1530 (TO-5 can size) integrated circuit devices that will dissipate approximately 150 MW each. At 140 MW dissipation, the MC 1530 device has a chip to case temperature drop of 12C. From Figure 3, it can be determined that at 450 MW total module dissipation, a case to base temperature drop of 18.5C can be expected. Allowing for the 1.5C temperature drop at the base to sink interface, results in a total chip to sink temperature gradient of 32C. This means that the MC 1530 chip temperature should not exceed 59C (32 + 27) mounted on a 27C sink.

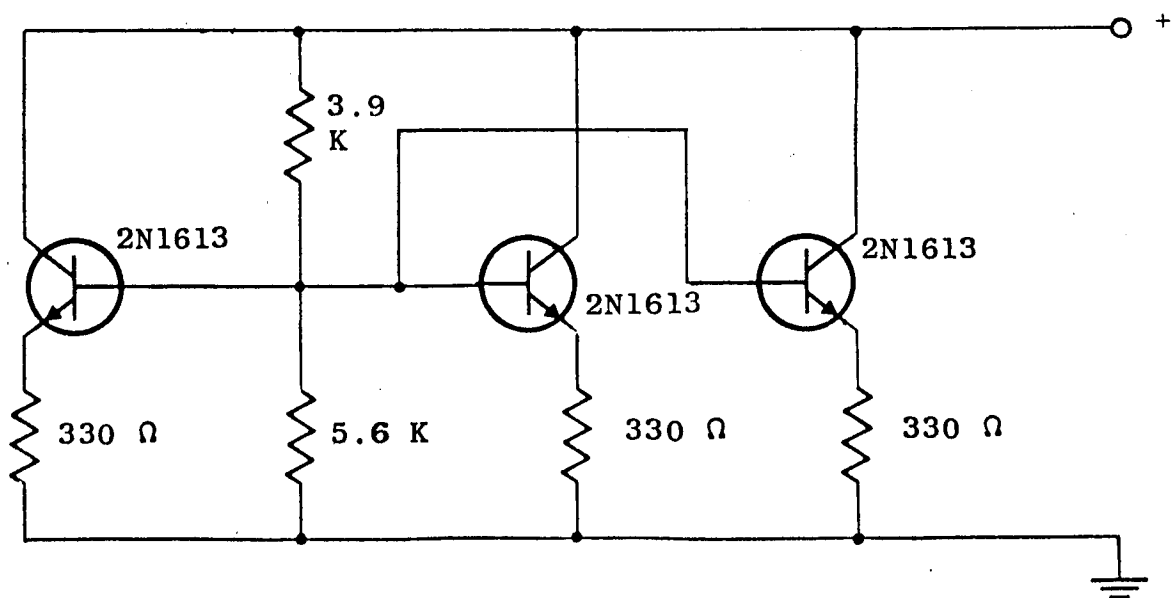
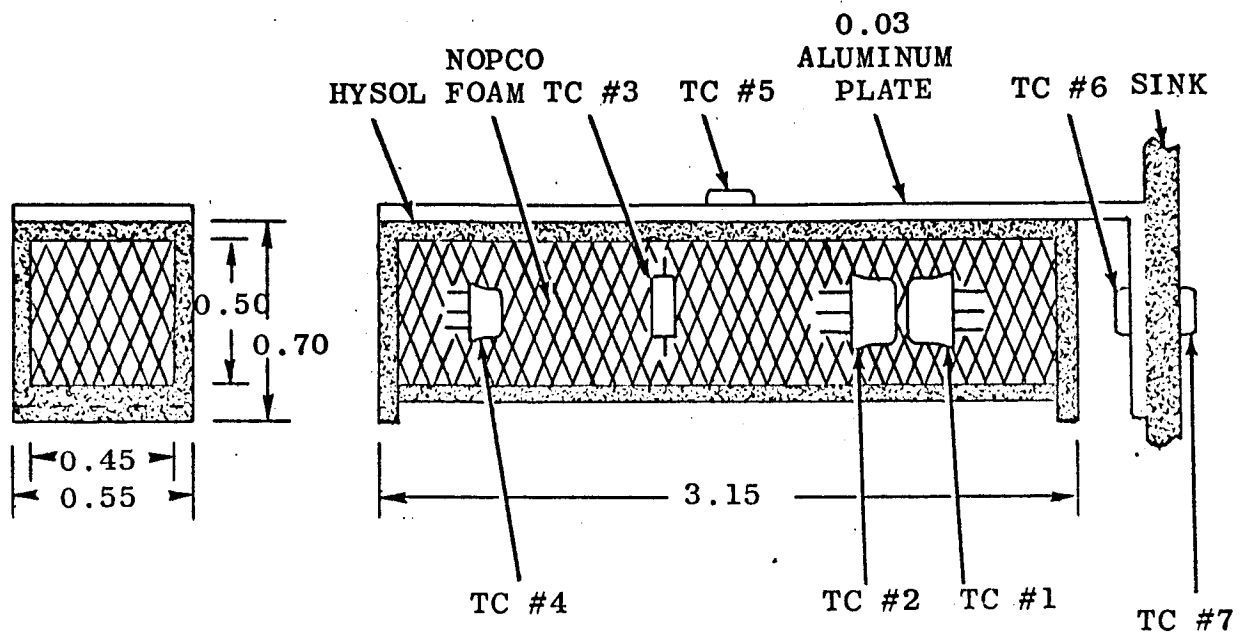


Figure 1. Cross-Section View and Wiring Schematic of the AROD Cordwood Thermal Test Module

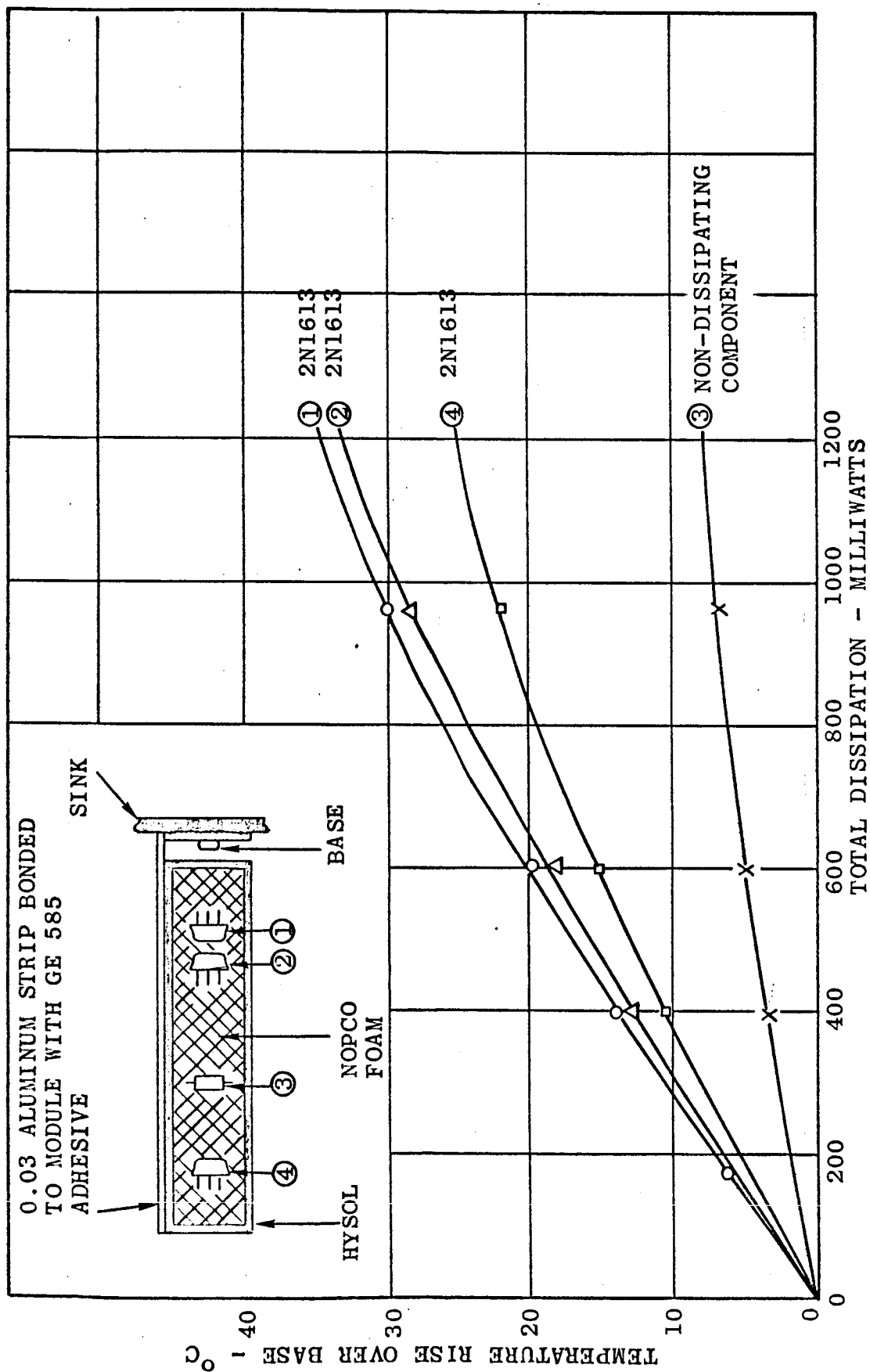


Figure 2. Temperature Rise vs Power Dissipation for a Typical AROD Cordwood Module (TM-5). Room Ambient Bench Test. Equal Dissipation from Each of the Three Transistors

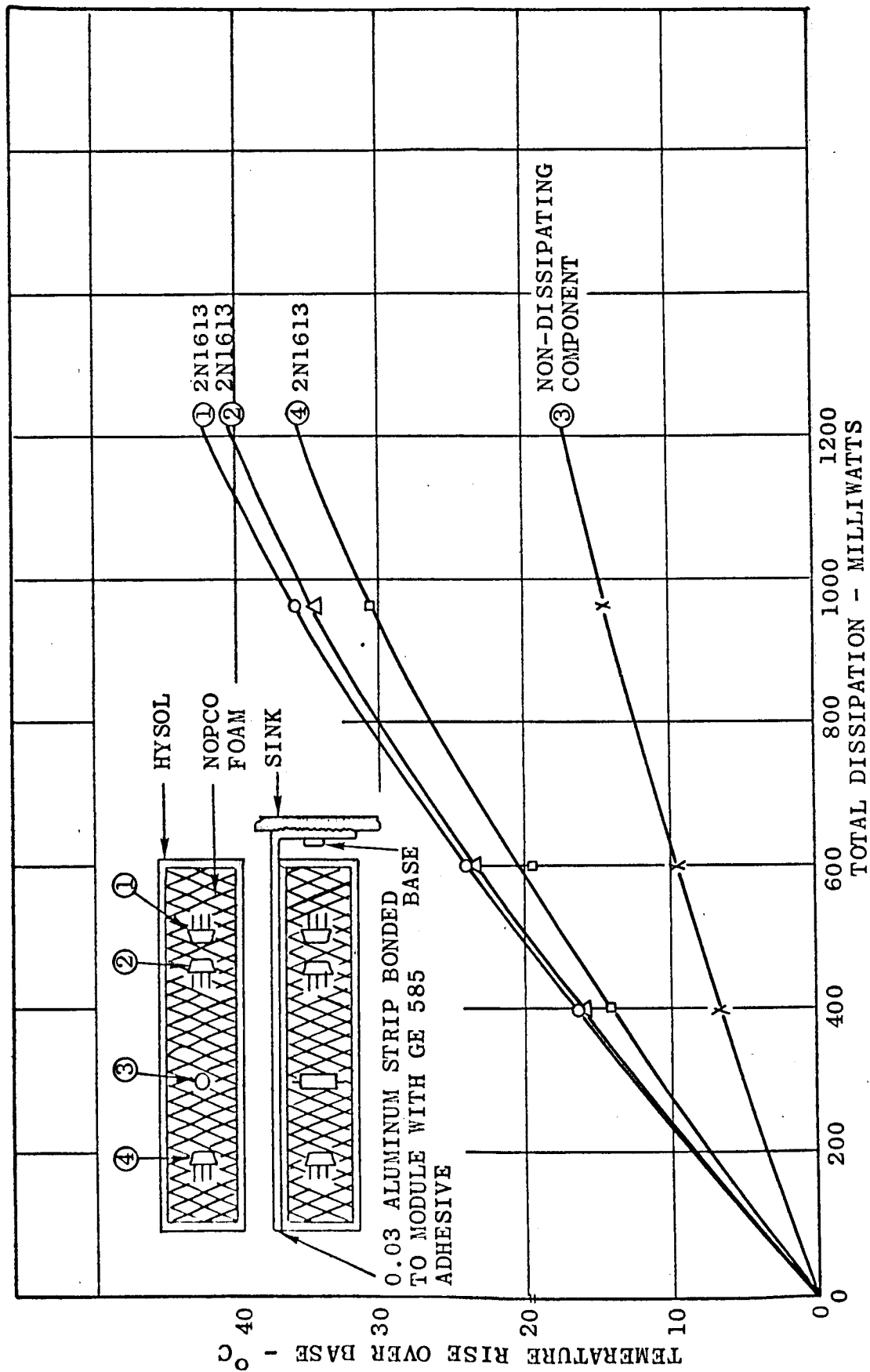


Figure 3. Temperature Rise vs Power Dissipation for a Typical AROD Cordwood Module (TM-5). Module Wrapped in Three Inches of Fiberglass Insulation for Test. Equal Dissipation From Each of the Three Transistors

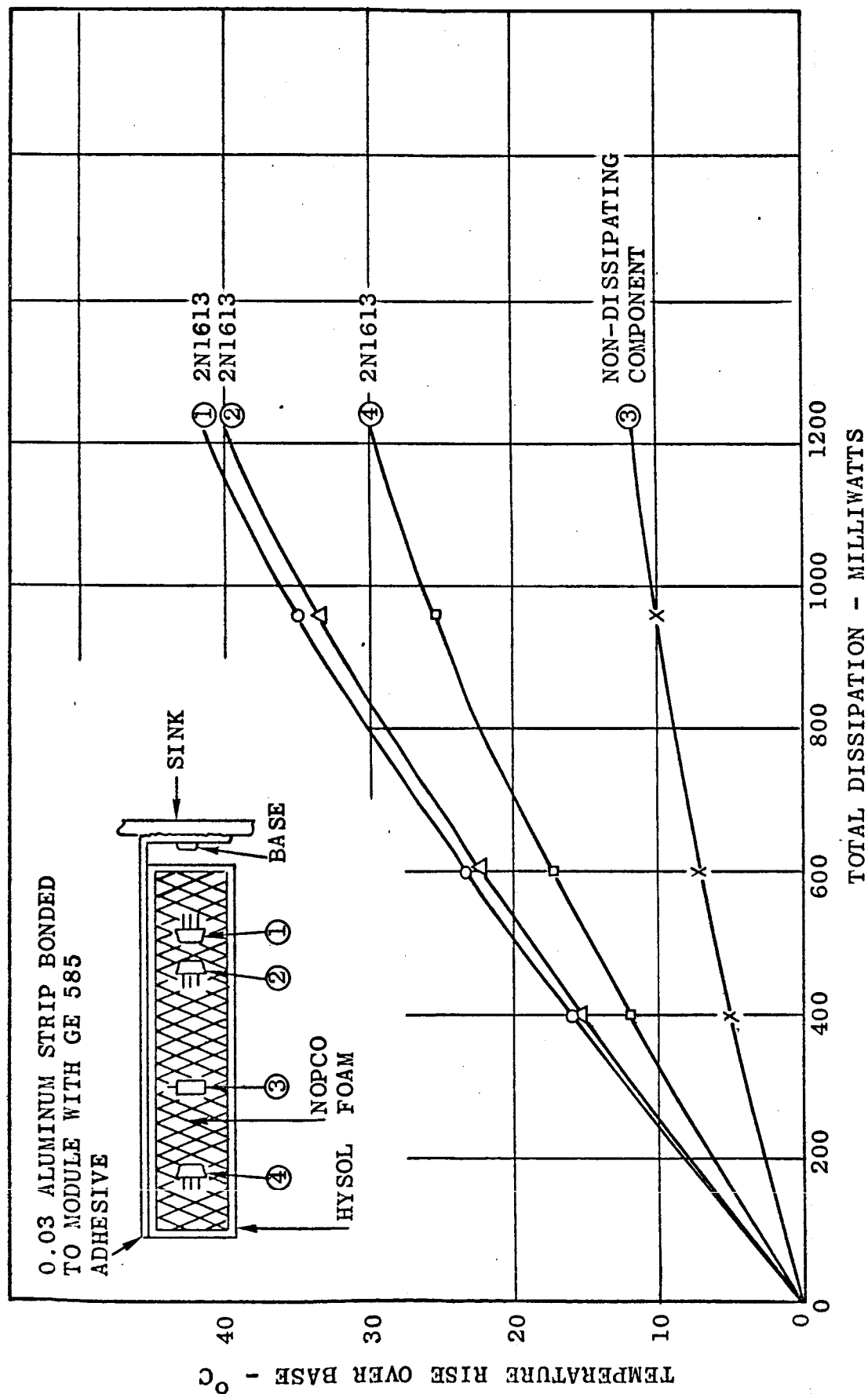


Figure 4. Temperature Rise vs Power Dissipation for a Typical AROD Cordwood Module (TM-5). Test Pressure Equal 1 x 10⁻⁵ mm Hg. Equal Dissipation from Each of the Three Transistors.

APPENDIX E

AROD VEHICLE BORNE EQUIPMENT
RELIABILITY ANALYSIS

AROD RELIABILITY ANALYSIS

1. PURPOSE

The purpose of this task is to analytically estimate the reliability achievable in the AROD Vehicle Borne Equipment excluding the TWTAs by application of Hi-Rel components.

2. SCOPE

The failure rates for this analysis have been derived from the Motorola Reliability and Components Group Special Memorandum No. -188 (SM-188), dated 1 September 1965.

These failure rates include out-of-tolerance or degradation failures as well as catastrophic or random failures for which no cause can be established. The failure rate of the soldered or welded connections is also included in the part failure rate.

For the purpose of this analysis, all parts are considered to be in a non-redundant configuration.

Component failure rates were computed using SM-188 in conjunction with the stress analysis data generated by the cognizant development engineer.

Typical failure rates for the most used components are listed in Appendix Number One.

Module failure rates are listed in Appendix Number Two.

Failure rates for subassemblies (frames) and connectors are listed in Appendix Number Three.

3. CONCLUSIONS

Based on a 200 hour mission, the estimated reliability achievable by application of a Hi-Rel program to the AROD Vehicle Borne Equipment is .968 (MTBF = 6,150 hours), see Appendix 4.

The multiplication factor for Hi-Rel parts given in SM-188 varies from .5 to .05. This results in approximately a

4 to 1 improvement in reliability for equipment using Hi-Rel parts. Therefore, based on a 200 hour mission, the estimated reliability of the AROD Test System Hardware is .878 (MTBF = 1537 hours).

APPENDIX 1

FAILURE RATES FOR THE MOST USED COMPONENTS

<u>COMPONENT</u>	<u>FAILURE RATE %/1000 HRS</u>	<u>QUANTITY USED</u>	<u>TOTAL</u>
MONOLITHIC I.C.	.0005	2609	1.3045
HYBRID I.C.	.0007	344	.3096
TRANSISTORS, SILICON	.0009	70	.0630
DIODES	.0008	223	.1864
CAPACITORS, CERAMIC	.0075	992	7.4400
CAPACITORS, TANTALUM	.0023	183	.4209
CAPACITORS, WET SLUG	.014	89	1.246
CAPACITORS, GLASS	.0006	181	.1086
R.F. CHOKES, FIXED	.0025	280	.7000
R.F. CHOKES, VARIABLE	.009	20	.1800
RF TRANSFORMERS	.0025	63	<u>.1575</u>
			12.1205

APPENDIX 2

MODULE FAILURE RATES

<u>DESIGNATION</u>	<u>NAME</u>	<u>ASSEMBLY DRAWING</u>	<u>% FAILURE PER 1000 HRS.</u>
1A2A1A1	-9 vdc FILTER	01-26213G	.0449
A2	8 MHz X5 MULTIPLIER	01-24581G	.0701
A3	7.6 MHz CONVERTER	01-24573G	.1027
A4	44.8 MHz CONVERTER	01-24567G	.1144
A5	12.8 MHz DOUBLER	01-24563G	.1000
A6	6.4 MHz DOUBLER	01-24561G	.1063
A7	MASTER OSCILLATOR		.0284
1A3A1A1	+9 vdc FILTER	01-26209G	.0449
A2	-9 vdc FILTER	01-26213G	.0449
A3	3.6 MHz X9 MULTIPLIER	01-24575G	.1244
A4	7.2 MHz DOUBLER	01-24577G	.0669
A5	8.4 MHz X7 MULTIPLIER	01-24579G	.0832
A6	XR LOOP VCO	01-24601G	.1190
A7	XR LOOP FIL. & CONV.	01-24599G	.0576
A8	300 KHz X3 MULTIPLIER	01-24583G	.1009
A9	+3.5 vdc FILTER	01-26201G	.0333
A10	VEH REF	01-23513G	.0086
A11	FREQ. DIV. MOD. I	01-23501G	.0101
A12	FREQ. DIV. MOD. IIA	01-23505G	.0102

MODULE FAILURE RATES (cont)

<u>DESIGNATION</u>	<u>NAME</u>	<u>ASSEMBLY DRAWING</u>	<u>% FAILURE PER 1000 HRS.</u>
1A3A1A13	FREQ. DIV. MOD. I	01-23501G	.0101
A14	FREQ. DIV. MOD. IIB	01-23509G	.0057
A15	FREQ. DIV. MOD. I	01-23501G	.0101
1A4A1A1	+9 vdc FILTER	01-26209G	.0449
A2	-9 vdc FILTER	01-26213G	.0449
A3	XN LOOP FIL. & CONV.	01-24593G	.0576
A4	XN LOOP VCO	01-24595G	.1190
A5	276 MHz X8 MULTIPLIER	01-26246G	.1009
A6	XQ LOOP. FIL. & CONV.	01-24587G	.0576
A7	XQ LOOP VCO	01-24589G	.0984
A8	108 MHz X4 MULTIPLIER	01-24597G	.0986
A9	32 MHz X5 MULTIPLIER	01-24565G	.0486
A10	217 MHz X2 MULTIPLIER	01-24585G	.1422
A11	217 MHz FILTER	01-29214G	.0025
1A6A1A1	CONT. DATA MODULATOR	01-24657G	.0266
A2	-15 vdc FILTER	01-26237G	.0189
A3	+3.5 vdc FILTER	01-26201G	.0333
1A6A2	MODULATION AMPLIFIER	01-24517G	.0120
1A6A3	PHASE MODULATOR	01-24516G	.1806
1A7A1A1	ACQUISITION MOD.	01-23555G	.0080
A2	MAX. RANGE & OLD/NEW STA. REG.	01-23397G	.0095

MODULE FAILURE RATES (cont)

<u>DESIGNATION</u>	<u>NAME</u>	<u>ASSEMBLY DRAWING</u>	<u>% FAILURE PER 1000 HRS.</u>
1A7A1A3	MAX. RANGE & OLD/NEW STA. REG.	01-23397G	.0095
A4	+3.5 vdc FILTER	01-26201G	.0333
A5	4 SEC. TIMER MOD.	01-24385G	.0085
A6	MAX. RANGE & OLD/NEW STA. REG.	01-23397G	.0095
A7	MAX. RANGE & OLD/NEW STA. REG.	01-23397G	.0095
A8	COMP. LOGIC & MEM. OUTPUT	01-23549G	.0095
1A7A2A1	MEM. CQNT. MOD.	01-24401G	.0065
A2	INPUT DATA CLOCK MOD.	01-23541G	.0080
A3	+3.5 vdc FILTER	01-26201G	.0333
1A8A1A1	DATA ENCODER MOD.	01-24389G	.0080
A2	TIMING BUFFER	01-24381G	.0060
A3	TIMING DIST. MOD. 2	01-23393G	.0100
A4	TIMING DIST. MOD. 1	01-23389G	.0100
A5	+3.5 vdc FILTER	01-26201G	.0333
1A8A2A1	MEM. WORD DECODE	01-23525G	.0220
A2	MEM. DIGIT & WORD DR.	01-23401G	.0071
A3	MEM WORD DR. MOD. B	01-24405G	.0350
A4	SENS. AMP. FILTER	01-26217G	.0470
A5	+9 vdc FILTER	01-26209G	.0449

MODULE FAILURE RATES (cont)

<u>DESIGNATION</u>	<u>NAME</u>	<u>ASSEMBLY DRAWING</u>	<u>% FAILURE PER 1000 HRS.</u>
1A8A2A6	MEMORY SYST. ASSY.	01-26424G	
A7	MEM. DR. MOD. A	01-24449G	.0060
A8	MEM. DIGIT & WORD DR.	01-23401G	.0071
A9	+3.5 vdc FILTER	01-26201G	.0333
A10	MEM. DIGITAL DEC. LOGIC	01-23521	.0085
1A9A1A1	LOAD MEM. LOGIC	01-23529G	.0085
A2	SYNC & ID VERIF. REG. MOD.	01-23533G	.0085
A3	SYNC & ID VERIF. MOD.	01-23545G	.0085
A4	OUTPUT DATA REG.	01-23537G	.0095
A5	+3.5 vdc FILTER	01-26201G	.0333
A6	OUTPUT DATA REG.	01-23537G	.0095
A7	SYNC & ID VERIF. MOD.	01-23545G	.0085
A8	SYNC & ID VERIF. REG.	01-23533G	.0085
A9	LOAD MEM. LOGIC	01-23529G	.0085
1A9A2A1	LOAD MEM. LOGIC	01-23529G	.0085
A2	SYNC & ID VERIF REG. MOD.	01-23533G	.0085
A3	SYNC & ID VERIF MOD.	01-23545G	.0085
A4	OUTPUT DATA REG.	01-23537G	.0095
A5	+3.5 vdc FILTER	01-26201G	.0333
A6	OUTPUT DATA REG.	01-23537G	.0095
A7	SYNC & ID VERIF. MOD.	01-23545G	.0085

MODULE FAILURE RATES (cont)

<u>DESIGNATION</u>	<u>NAME</u>	<u>ASSEMBLY DRAWING</u>	<u>% FAILURE PER 1000 HRS.</u>
1A9A2A8	SYNC & ID VERIF. REG.	01-23533G	.0085
A9	LOAD MEM. LOGIC	01-23529G	.0085
2A1A1A1	FILTER REG. T	01-24553G	.0669
A2	LOOP FILTER Gc GATE	01-24676H	.0826
A3	6 MHz VCO	01-24503G	.0750
A4	BAL. DET. Q	01-24495	.1006
A5	BAL. DET. I	01-24495	.1006
A6	AMPL. & A _L DEMOD.	01-24513G	.1006
A7	LIM. & AGC AMPLIFIER	01-24491G	.1434
A8	2nd MIXER 7.2 MHz	01-24593H	.0874
A9	2nd IF AMPLIFIER	01-24489G	.0902
A10	1st MIXER	01-24505G	.0858
A11	DEMODULATOR	01-24485G	.0769
2A2A1A1	FILTER REG. M	01-24551G	.0669
A2	A _L - A _H DATA MAT. FIL.	01-24525G	.1476
A3	A _H & DATA DEMODULATOR	01-24523G	.0231
A4	RANGE LOOP FILTER	01-24531G	.0993
A5	12.7 MHz VCO & MIXER	01-24533G	.1159
A6	12.8 MHz VCO & FILTER	01-24535G	.1797
A7	DIVIDE BY 141	01-24397G	.0092
A8	FREQ. PRESET	01-23404G	.0432

MODULE FAILURE RATES (cont)

<u>DESIGNATION</u>	<u>NAME</u>	<u>ASSEMBLY DRAWING</u>	<u>% FAILURE PER 1000 HRS.</u>
2A2A1A9	+3.5 vdc FILTER	01-26201G	.0333
A10	H CODE SEARCH	01-29193G	.0189
A11	DOPPLER MIXER	01-24509G	.0924
A12	DOPPLER MULTIPLIER	01-24507G	.1230
2A3A1A1	L SEQUENCE GENERATOR	01-27105F	.0090
A2	S-BAND DATA ENCODER	01-27113F	.0085
A3	+3.5 vdc FILTER	01-26201G	.0333
A4	-3.5 vdc FILTER	01-26205G	.0333
A5	INPUT CONT.	01-27121F	.0085
A6	PROGRAM. COUNT. & D/O TIMER	01-27117F	.0090
A7	VEH REC. CODE BUFFER	01-23361G	.0085
A8	VEH REC. CODE COMB. 2	01-27133F	.0175
A9	VEH REC. CODE COMB. 1	01-27129F	.0080
2A3A2A1	-3.5 vdc FILTER	01-26205G	.0333
A2	A _L - A _H & DATA DEMOD.	01-24470G	.0661
A3	RANGE EXT. INTERFACE	01-26165G	.0155
A4	VEH REC. CODE GATE GEN.	01-27137F	.0085
A5	VEH REC. CODE RETIMER	01-23365G	.0080
A6	CODE CLOCK GEN.	01-26957F	.0091
A7	GR GATE	01-26229G	.0040
A8	+3.5 vdc FILTER	01-26201G	.0333

MODULE FAILURE RATES (cont)

<u>DESIGNATION</u>	<u>NAME</u>	<u>ASSEMBLY DRAWING</u>	<u>% FAILURE PER 1000 HRS.</u>
2A3A2A9	H SEQ. GENERATOR	01-27101F	.0085
A10	R/A TIMER	01-27125F	.0085
2A13A1A1	RANGE EXT. MOD. 4	01-26153G	.0658
A2	RANGE EXT. MOD. 4	01-26153G	.0658
A3	RANGE EXT. MOD. 4	01-26153G	.0658
A4	RANGE EXT. MOD. 4	01-26153G	.0658
A5	+9 vdc FILTER	01-26209G	.0449
A6	+3.5 vdc FILTER	01-26201G	.0333
A7	6.35 MHz OSCILLATOR	01-26244G	.0767
A8	RANGE EXT. MOD. 5	01-26157G	.0601
2A13A2A1	CLOCK PULSE GEN. 4	01-23433G	.0235
A2	D.R. STORE 4 MOD. 16	01-23441G	.0085
A3	D.R. STORE 4 MOD. 14	-1-23423G	.0080
A4	RANGE EXT. MOD. 2	01-26145G	.0096
A5	RANGE EXT. MOD. 2	01-26145G	.0096
A6	+3.5 vdc FILTER	01-26201G	.0333
A7	RANGE EXT. MOD. 2	01-26145G	.0096
A8	RANGE EXT. MOD. 2	01-26145G	.0096
A9	D.R. STORE 4 MOD. 13	01-23457G	.0080
2A14A1A1	RANGE EXT. MOD. 3	01-26149G	.0135
A2	RANGE EXT. MOD. 1	01-26141G	.0163

MODULE FAILURE RATES (cont)

<u>DESIGNATION</u>	<u>NAME</u>	<u>ASSEMBLY DRAWING</u>	<u>% FAILURE PER 1000 HRS.</u>
2A14A1A3	S-BAND DATA ENC.	01-27113F	.0085
A4	L SEQ. GENERATOR	01-27105F	.0090
A5	+3.5 vdc FILTER	01-26201G	.0333
A6	XMTR GR GATE	01-26254G	.0025
A7	-3.5 vdc FILTER	01-26205G	.0333
A8	VEH XMTR CODE COMB.	01-27109F	.0265
A9	CODE CLOCK GENERATOR	01-26957F	.0091
A10	H SEQ. GENERATOR	01-27101F	.0085
2A14A2A1	D.R. STORE 4 MOD. 15	01-23486G	.0090
A2	RANGE EXT. MOD. 1	01-26141G	.0163
A3	RANGE EXT. MOD. 3	01-26149G	.0135
A4	D.R. STORE 4 MOD. 12	01-23457G	.0080
A5	+3.5 vdc FILTER	01-26201G	.0333
A6	RANGE EXT. MOD. 3	01-26149G	.0135
A7	RANGE EXT. MOD. 1	01-26141G	.0163
A8	RANGE EXT. MOD. 1	01-26141G	.0163
A9	RANGE EXT. MOD. 3	01-26149G	.0135
2A15A1A1	D.R. VEL. DATA MOD. 9	01-23449G	.0080
A2	VEH. VEL. EXT. MOD. 1	01-26949F	.0086
A3	D.R. VEL. DATA MOD. 11	01-23453G	.0070
A4	VEH. VEL. EXT. MOD. 2	01-26953F	.0090

MODULE FAILURE RATES (cont)

<u>DESIGNATION</u>	<u>NAME</u>	<u>ASSEMBLY DRAWING</u>	<u>% FAILURE PER 1000 HRS</u>
2A15A1A5	+3.5 vdc FILTER	01-26201G	.0333
A6	D.R. VEL DATA MOD 10	01-23453G	.0070
A7	VEH VEL EXT MOD 1	01-26949G	.0086
A8	D.R. VEL DATA MOD 8	01-23449G	.0080
A9	D.R. STORE 4 MOD 17	01-23468G	.0090
2A15A2A1	TIMING CONT. GEN. MOD 2	01-23425G	.0090
A2	TIMING CONT. GEN. MOD 1	01-23421G	.0080
A3	CLOCK PULSE GEN. MOD 3	01-23429G	.0085
A4	STORE 4 MOD 18	01-23472G	.0075
A5	+3.5 vdc FILTER	01-26201G	.0333
A6	L127 COUNTER	01-26941F	.0085
A7	RESET LOGIC GEN.	01-26945F	.0080
A8	INTERFACE & RESET CONT.	01-26933F	.0091
A9	DIVIDE BY 2500	01-26937F	.0080
2A16A1A1	TIME LABEL MOD. 3	01-26929F	.0080
A2	TIME LABEL MOD. 2	01-26925F	.0080
A3	TIME LABEL MOD. 1	01-26921F	.0085
A4	+3.5 vdc FILTER	01-26201G	.0333
A5	D.R. STORE 1 MOD 20	01-23480G	.0070
A6	D.R. STORE 1 MOD 19	01-23476G	.0080
A7	D.R. OUTPUT REG. MOD 7	01-23445G	.0090

MODULE FAILURE RATES (cont)

<u>DESIGNATION</u>	<u>NAME</u>	<u>ASSEMBLY DRAWING</u>	<u>% FAILURE PER 1000 HRS.</u>
2A16A2A1	D.R. STORE 1 MOD 23	01-23480G	.0070
A2	D.R. STORE 1 MOD 22	01-23480G	.0070
A3	VEH. VEL. EXT. MOD 1	01-26949F	.0086
A4	D.R. STORE 1 MOD 21	01-23480G	.0070
A5	+3.5 vdc FILTER	01-26201G	.0333
A6	VEH. VEL. EXT. MOD 2	01-26953F	.0090
A7	D.R. OUTPUT REG. MOD 5	01-23437G	.0090
A8	VEH. VEL. EXT. MOD 1	01-26949F	.0086
A9	D.R. OUTPUT REG. MOD 6	01-23437G	.0090

APPENDIX 3

PERCENT FAILURE PER 1000 HOURS

CASE 1

1A1	R. F. CONVERTER	.1200
1A2	FREQ. SYNTHESIZER #1	.5384
1A3	FREQ. SYNTHESIZER #2	.7299
1A4	FREQ. SYNTHESIZER #3	.8152
1A5	VEH. TRACK. TRANSMITTER	.2286
1A6	STATION CONTROL XMTR	.2714
1A7	SYSTEM CONT. LOGIC ASSY 3	.1451 (1A7A1 - .0973, 1A7A2 - .0478)
1A8	SYSTEM CONT. LOGIC ASSY 2	.2782 (1A8A1 - .0673, 1A8A2 - .2109)
1A9	SYSTEM CONT. LOGIC ASSY 1	.2066 (1A9A1 - .1033, 1A9A2 - .1033)
1A10	POWER CONVERTER	<u>.1348</u>
	TOTAL	3.4672

APPENDIX 3

PERCENT FAILURE PER 1000 HOURS

CASE 2

2A1	CTL A	1.0100
2A2	MTL A	.9525
2A3	RCC A	.3304 (2A3A1 .1356 - 2A3A2 .1948)
2A4	CTL B	1.0100
2A5	MTL B	.9525
2A6	RCC B	.3304
2A7	CTL C	1.0100
2A8	MTL C	.9525
2A9	RCC C	.3304
2A10	CTL D	1.0100
2A11	MTL D	.9525
2A12	RCC D	.3304
2A13	D.M. 4	.5979 (2A13A1 .4782 - A2 .1197)
2A14	D.M. 3	.3002 (A1 .1605 - A2 .1397)
2A15	D.M. 2	.1984 (A1 .0985 - A2 .0999)
2A16	D.M. 1	.1803 (A1 .0818 - A2 .0985)
2A17	DIST. AMP.	<u>.1480</u> (A1 .0535 - A2 .0535 - A3 .0410)
	TOTAL	10.5964

APPENDIX 3

PERCENT FAILURE PER 1000 HOURS

CONNECTORS

Hook-up Connections	$1400 \times .0012 = 1.6800$
RF (coax) Connections	$80 \times .005 = .4000$
<u>Total</u>	<u>2.0800</u>

PERCENT FAILURE PER 1000 HOURS

EXCLUDING VTR

Case I	3.4672
2A13	.5979
2A14	.3002
2A15	.1984
2A16	.1803
2A17	.1480
Connectors	<u>2.0800</u>
<u>Total</u>	<u>6.9720</u>

PERCENT FAILURE PER 1000 HOURS

FAILURE RATE PER VTR CHANNEL

2A1	1.0100
2A2	.9525
2A3	<u>.3304</u>
<u>Total</u>	<u>2.3129</u>

APPENDIX 4

CALCULATION OF RELIABILITY FOR A 200 HOUR MISSION

For a 200 hour mission, the reliability, excluding the VTR, is:

$$\text{Rel/without VTR} = e^{-T(\text{F.R.})} = e^{-(200)(.00006972)} = .9861$$

The reliability of each VTR channel is:

$$\text{Rel/Channel} = e^{-T(\text{F.R.})} = e^{-200(.000023129)} = .9954$$

The reliability for any three of four channels is:

$$\text{Rel (3 of 4 Ch)} = (\text{Rel/Ch})^4 + 4(\text{Rel/Ch})^3 \left(1 - \frac{\text{Rel}}{\text{Ch}}\right) = 0.9998$$

The net equipment reliability is:

$$R_T = \text{Rel/without VTR} \times \text{Rel (3 of 4 Ch)} = .9861 \times .9998$$

$$\text{Reliability} = .986$$

Reliability for 100% operation is:

$$\text{Rel} = (.9861) \times (.9954)^4 = 0.968$$

APPENDIX F

**AROD. GROUND STATION EQUIPMENT
RELIABILITY ANALYSIS**

AROD RELIABILITY ANALYSIS

1. PURPOSE

The purpose of this task is to analytically estimate the reliability achievable in the AROD Ground Station Equipment by application of Hi-Rel components.

2. SCOPE

The failure rates for this analysis have been derived from the Motorola Reliability and Components Group Special Memorandum No. -188 (SM-188), dated 1 September 1965.

These failure rates include out-of-tolerance or degradation failures as well as catastrophic or random failures for which no cause can be established. The failure rate of the soldered or welded connections is also included in the part failure rate.

For the purpose of this analysis, all parts are considered to be in a non-redundant configuration.

Component failure rates were computed using SM-188 in conjunction with the stress analysis data generated by the cognizant development engineer.

Typical failure rates for the most used components are listed in Appendix Number One.

Failure rates for subassemblies (frames) are listed in Appendix Number Two. However, these rates do not include connectors. Connector failure rates were computed separately.

3. CONCLUSIONS

Based on a 200 hour mission, the estimated reliability achievable by application of a Hi-Rel program to the AROD Ground Station Equipment is .978 (MTBF = 9,023 hours), see Appendix 3.

The multiplication factor for Hi-Rel parts given in SM-188 varies from .5 to .05. This calculates out to approximately a 4 to 1 increase in reliability.

Based on a 200 hour mission, the estimated reliability of the AROD Test System Hardware is .9113 (MTBF = 2,255 hours).

APPENDIX 1

Typical Failure Rates for Components

<u>Component</u>	<u>Failure Rate %/1000 Hours</u>	<u>Quantity Used</u>	<u>Total</u>
Monolithic I/C	.0005	376	.1880
Hybrid I/C	.0007	68	.0612
Transistor, Silicon	.0009	153	.1377
Diodes	.0008	73	.0584
Capacitor, Ceramic	.0075	443	3.3225
Capacitor, Tantalum	.0023	101	.2323
Capacitor, Mica	.0002	271	.0542
RF Chokes, Fixed	.0025	213	.5325
RF Chokes, Variable	.0090	107	.9630
Transformers	.0025	99	.2475
			<u>5.7973</u>

APPENDIX 2

Percent Failure per 1000 Hours

<u>Reference Designation</u>	<u>Subassembly Title</u>	<u>Failure Rate %/1000 Hours</u>
1A1A1	Filter, Bandpass - VHF	.004
1A1A2	Converter, Frequency Electronic VHF	.2119
1A1A3	Amplifier, Intermediate Frequency Automatic Gain Control	.2863
1A1A4	Generator, Local Oscillator Reference	.4138
1A1A5	Oscillator, Voltage Controlled 17 MHz	.2085
1A1A6	Detector, Radio Frequency	.5796
1A1A7	Synthesizer, Electrical Frequency	.3678
1A1A8	Oscillator - Frequency Preset	.3372
1A1A9	Frequency Divider - Frequency Preset	.0970
1A1A10	Data Demodulator No. 1	.1548
1A1A11	Data Demodulator No. 2	.1687
1A1A12	Logic, Station Control	.0943
1A1A13	Three Power Supplies	<u>.3000</u>
		3.2239

APPENDIX 2 (cont'd)

<u>Reference Designation</u>	<u>Subassembly Title</u>	<u>Failure Rate %/1000 Hours</u>
1A2A1	Converter, Frequency Electronic S-Band	.0513
1A2A2	Frequency Multiplier - X14	.3752
1A2A3	Frequency Multiplier - X5/16	.3357
1A2A4	Oscillator, Voltage Controlled - 12.8 MHz	.3939
1A2A5	Mixer, Intermediate Frequency	.2124
1A2A6	Amplifier, Intermediate Frequency 8 MHz	.1158
1A2A7	Detector, Radio Frequency - 8 MHz	.5044
1A2A8	Detector, Radio Frequency - Ranging Loop	.3997
1A2A9	Detector, Radio Frequency - Frequency Preset	.1910
1A2A10	Mixer, Doppler	.2157
1A2A11	Detector, Radio Frequency - 38.4 MHz	.2027
1A2A12	Oscillator, Voltage Controlled - Doppler	.2384
1A2A13	Detector, Radio Frequency - Doppler Sign	.0395
1A2A14	Mixer - Synthesizer Loop	.2670
1A2A15	Frequency Divider - Synthesizer	.1503
1A2A16	Oscillator, Voltage Controlled - Synthesizer Loop	.5007
1A2A17	Frequency Multiplier - Modulator - X2	.1446
1A2A18	Frequency Multiplier - Modulator - X8	.3395

APPENDIX 2 (cont'd)

<u>Reference Designation</u>	<u>Subassembly Title</u>	<u>Failure Rate %/1000 Hours</u>
1A2A19	Code Control Receiver #1	.1222
1A2A20	Code Control Receiver #2	.1432
1A2A21	Bias Converter - Filter	.0554
1A2A22	Acquisition Unit	.0080
		<u>5.0076</u>

APPENDIX 2 (cont'd)

<u>Reference Designation</u>	<u>Subassembly Title</u>	<u>Failure Rate %/1000 Hours</u>
1A3A3	Two Relays	.2000
1A3A4	Three Power Supplies and Filter	<u>.3000</u> .5000
1A4	AC-DC Converter	.1510

APPENDIX 2 (cont'd)

Percent Failure per 1000 Hours

CONNECTORS

Hook-up Connectors	$947 \times .0015 = 1.4205$
RF (coax) Connectors	$156 \times .005 = \underline{.7800}$
	2.2005

APPENDIX 3

Calculations for Reliability for a 200 Hour Mission

$$Rel = e^{-T(F.R.)}$$

$$F.R. (Total) = F.R. \text{ of all subassemblies}$$

$$+ F.R. \text{ of relays}$$

$$+ F.R. \text{ of power supplies}$$

$$+ F.R. \text{ of AC to DC converter}$$

$$+ F.R. \text{ of connectors}$$

$$= 3.2239 + 5.0076 + .5000 + .1510 + 2.2005$$

$$F.R. = 11.0830 \text{ percent per thousand hours}$$

$$Rel = e^{-(200)(.00011083)} = e^{-.022166}$$

$$Rel = 0.978$$